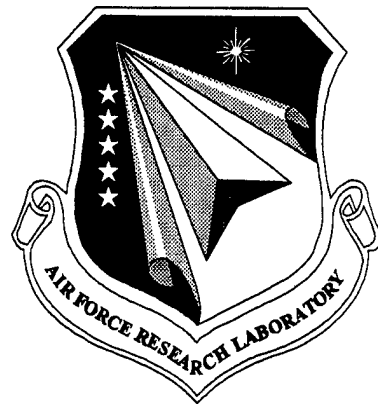


AFRL-ML-WP-TR-1998-4211

**ENDURANCE PUMP TESTS WITH
FRESH AND PURIFIED MIL-H-5606
HYDRAULIC FLUID**



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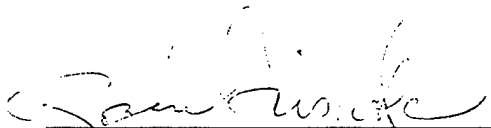
This technical report has been reviewed and is approved for publication.



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1.0 INTRODUCTION

Used hydraulic fluid is one of the largest contributors to the waste stream generated at most US Air Force bases. It is a similar problem for the US Navy aircraft, both land and carrier based. In most cases, the used hydraulic fluid collected is the by-product of an aircraft maintenance action in which some component is being replaced, repaired, etc. The fluid is not being changed because it is "worn out" or extremely contaminated. However, this used fluid is collected in rather large quantities for disposal. It is estimated the Air Force alone uses approximately 1,000,000 gallons of hydraulic fluid per year, much of that in replacing hydraulic fluid lost during maintenance actions. Another source of used hydraulic fluid is ground service equipment which is routinely hooked up to aircraft when the aircraft are serviced. The main purpose of this servicing is to replenish hydraulic fluid which may have been lost due to leakage as well as to provide hydraulic power to check hydraulic system/component performance. The hydraulic fluid coming out of the aircraft is significantly more contaminated than new fluid going in, which is to be expected. The level of contamination is generally not too high for acceptable performance of the aircraft hydraulic system, but is too contaminated to be re-introduced into the aircraft in many cases, which generates more waste stream for disposal.

The armed services have investigated possible avenues to reduce or eliminate this waste stream. The two primary approaches have been reclamation [1] and purification. The reclamation approach has some inherent problems including collection and the need to conduct conformance checks on the quality of the hydraulic fluid before it can be repackaged and sold as used/new fluid. The cost of these conformance checks, which must be performed on every batch of reclaimed fluid, coupled with the relatively low cost of new fluid, has essentially eliminated this approach on the basis of economics. The purification approach, however, appears to be quite cost effective due to the ease of the process, the fact the fluid never leaves the site at which the used fluid is generated and the fewer tests which need to be conducted to assure adequate performance.

All three US armed services have, to some extent, utilized fluid purification as a means to minimize their hydraulic fluid waste stream. One of the problems with the utilization has been the lack of documentation of testing done to assure the used fluid has been adequately purified and the purified fluid is acceptable for use in these very expensive weapons systems. One exception is the work done by the Army [1] in which they found through field tests of purified MIL-H-46170 in ground vehicles that purified hydraulic fluid provided acceptable performance in hydraulic systems if the used fluid was mixed with new fluid as it was added to the vehicle's hydraulic system. As far as the authors have been able to discern, the main factors investigated by most potential users in assessing whether or not hydraulic fluid purifiers could be used to reduce the hydraulic fluid waste stream were the contamination levels (i.e., particulate, water and halogenated solvent) in the hydraulic fluid after it had been purified. That does not address the possible deterioration of the fluid during use or the potential for the purifier to remove some of the performance improving additives from the

fluid as well as the contaminants. If the mean time between failure of a hydraulic system component were reduced by as little as 10-20%, the economics of using fluid purification to reduce the cost of operation by minimizing the waste stream would probably not be very attractive. Additionally, it would be difficult to detect such a small, but significant change in component life until the purified fluid had been applied across the fleet and an extensive drain, purge and fill program would be required to remedy the problem. It was felt that a long term hydraulic component test under carefully controlled conditions would be advisable to assess the potential negative effect a fluid purifier could have on hydraulic fluid performance. Since the hydraulic pump in a system is generally considered to be the component most sensitive to most of the properties of a hydraulic fluid (e.g., viscosity, lubricity, foaming, etc.), it was selected to be the test article. The in-house pump testing of fresh and purified MIL-H-5606 hydraulic fluid is the subject of this report.

NOTE: The use of the PALL Purifier in this program does not constitute endorsement of the unit. It was selected for these tests for two reasons: 1) this unit was already owned by the Air Force and was provided by to us by Eglin Air Force Base; and 2) identical units are the ones most widely used in the field. Testing other brands and models of purifiers was beyond the scope of this program.

2.0 TEST OBJECTIVE

The objective of this program was to perform endurance pump testing using both fresh and purified MIL-H-5606 hydraulic fluid, to study the impact of fluid purification on pump life, and to determine if fluid purification has any adverse effect on pump life.

3.0 APPROACH

The approach proposed and approved was to run long term tests with both fresh and purified MIL-H-5606 hydraulic fluid in the AFRL/MLBT in-house pump test facility. Fluid samples were taken at selected intervals during both tests and key physical and chemical properties were determined. The pump operating characteristics were monitored and the pump was disassembled for visual inspection periodically during both tests.

The 1500 hour tests were run on two F-16 Emergency Power Unit (EPU), Vickers Model PV3-075-15, to determine if purifying the hydraulic fluid was acceptable from the standpoint of fluid properties and pump wear. The test pump is a constant pressure, variable displacement pump rated at 22.7 gpm, 3000 psig, and 7500 rpm. If the purifier removed any of the additives from the fluid, it could make the fluid unacceptable for reuse. Also, if the fluid properties were changed significantly, it could affect pump performance and/or wear.

A baseline test was conducted using MIL-H-5606 hydraulic fluid without sending the fluid through the purifier. The second test was conducted with hydraulic fluid which was circulated for 40 minutes through the PALL purifier after every 200 hours (approx.) during the test. A

comparison of the pump test results was carried out to see if fluid purification had any adverse effect on pump life.

Each pump was initially disassembled to photograph the parts and then again at 972 hours to check pump wear and photograph the parts. At the conclusion of each test, the pump was disassembled once more and photographed.

3.1 PUMP TEST PLAN

TEST FLUIDS:

TEST 35: Fresh MIL-H-5606
TEST 36: Purified MIL-H-5606

TEST PUMP:

F-16 EPU/Vickers Model PV3-075-15 Pump (new or rebuilt pump for each test)

PRE-TEST/POST TEST INSPECTION:

1. Partially disassemble the pump to inspect the valve plate, cylinder barrel, pistons, piston-shoes, yoke and other critical surfaces. Mark the pistons and the corresponding cylinder bores (with Kimwipe) to make sure the pistons go back in their corresponding original cylinder bores during reassembly.
2. Take the necessary photographs to document the general condition of the pump, with minimum disassembly.

TEST CONDITIONS:

Pump Shaft Speed: 5000 rpm
Pump Inlet Pressure: 70 psig
Pump Outlet Pressure: 3000 psig
Max Fluid Temperature: 255 °F
Pump Outlet Flow: Cycle between 12.5 gpm and 3 gpm every minute

TEST DURATION: 1500 total hours or performance degradation, whichever comes first

PERFORMANCE PARAMETERS:

Flow Rates: pump case drain and pump outlet
Pressure: pump outlet

Temperatures: pump inlet, pump outlet, case drain
Heat Rejection Rate:
Torque: torque sensor between hydraulic pump and motor drive unit

TEST 35:

1. Fill the test stand with MIL-H-5606 and bleed any undissolved air out of the stand.
2. Start the pump under low load (approx. 3 gpm main flow) and increase speed to 5000 rpm.
3. Stabilize the fluid temperature so the maximum temperature in the circuit is 250-255°F (usually in the case drain).
4. Take 50 ml fluid sample at 0 (right after bleeding the stand), at 50 and 100 hours and at every 100 hours thereafter.

TEST 36:

1. Purify the fresh MIL-H-5606.
2. Fill the test stand with the purified fluid and bleed.
3. Start the pump under low load (approx. 3 gpm main flow) and increase speed to 5000 rpm.
4. Stabilize the fluid temperature so the maximum temperature in the circuit is 250-255 °F (usually in the case drain).
5. Take 50 ml sample after 100 hours of running.
6. Take 150 ml sample at 200 hours and stop the test.
7. Drain the stand and run the test fluid through the purifier for 40 minutes. Take a 150 ml sample of the purified fluid.
8. Fill the stand with the test fluid (from step 7) and bleed.
9. Repeat steps 3 through 8 at 400, 600, and 800 hours.
10. Between 946 hours and 972 hours, run the test under full flow (12.5 gpm) conditions.
11. Take a fluid sample and stop the test.
12. Disassemble the pump for inspection and photography.
13. Drain the stand and run the test fluid through the purifier for 40 minutes. Take a 150 ml sample of the purified fluid.
14. Assemble the pump and mount it on the stand.
15. Fill the test stand with the purified test fluid (from step 13) and bleed.
16. Repeat steps 3 through 8 at 1200 hours and 1400 hours.
17. Stop the tests after 1500 total hours or when degradation of performance is observed.

3.2 HYDRAULIC PUMP TEST STAND

The pump test stand at AFRL/MLBT was designed primarily for testing new and experimental hydraulic fluids using small to medium displacement aircraft hydraulic pumps. This test stand as shown in Figure 1 has been described in previous publications [3, 4].

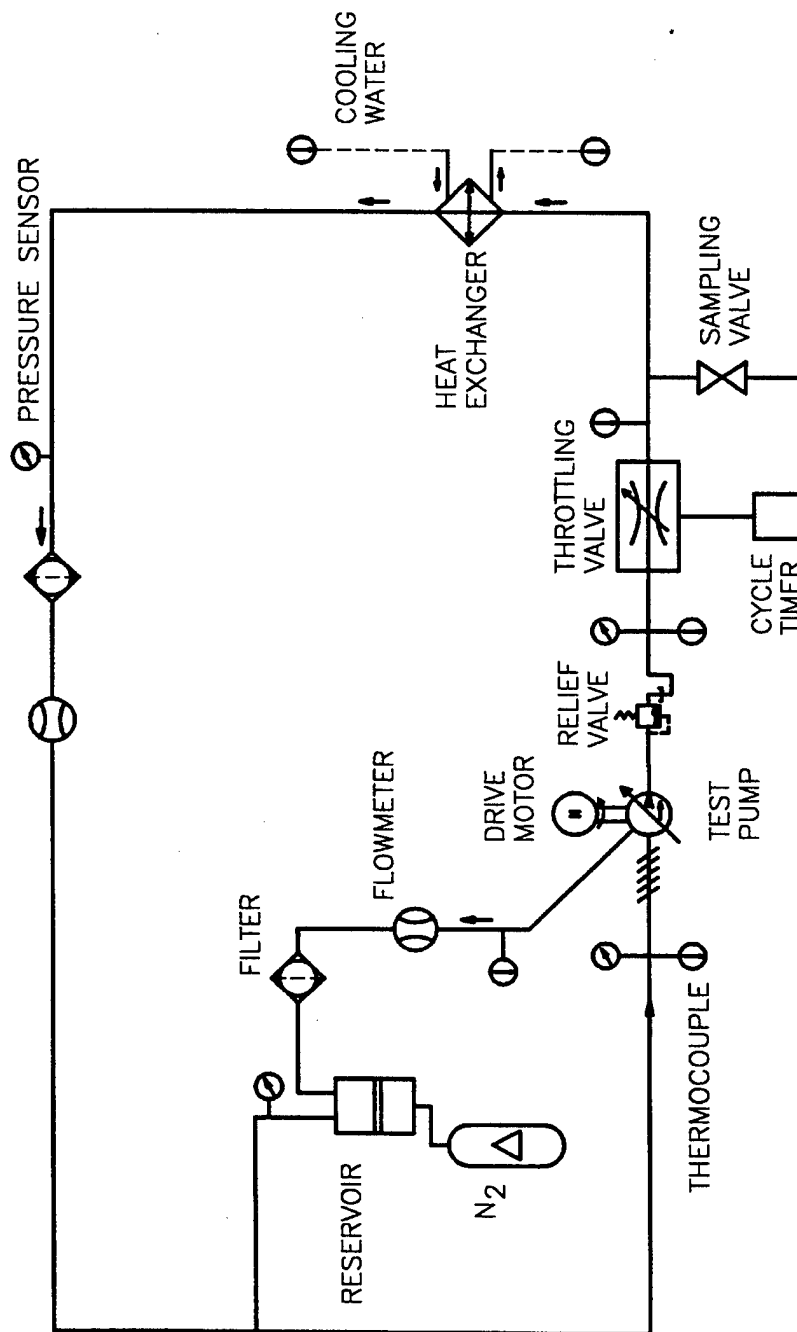


FIGURE 1: HYDRAULIC PUMP TEST CIRCUIT

3.3 PALL PORTABLE FLUID PURIFIER

The portable purifier (PLM Model PE 00440-1Z) purifier is designed to remove water, air, chlorinated solvents, and solid contaminants from lubricating, hydraulic and heat transfer fluids. The purifier is a portable system requiring an open space close to the contaminated fluid reservoir and ready access to the required electrical power. A schematic of the purifier is shown in Fig. 2.

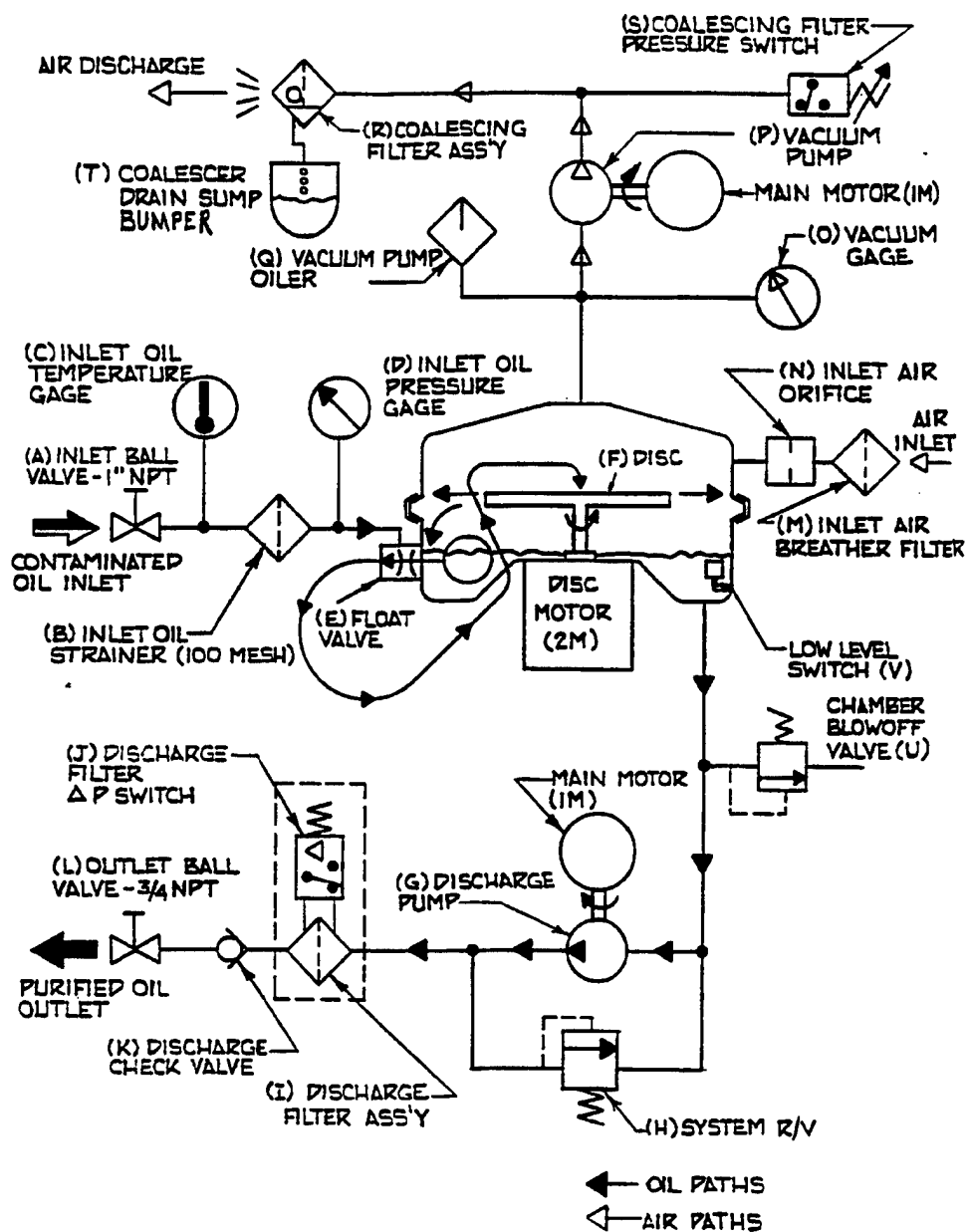


Figure 2. Fluid Purifier Schematic

Fluid Purifier Specifications:

Inlet Fluid Temp:	+145 °F (max)/62 °C (max)
Fluid Circulation Rate:	3 gpm (max)
Operating Viscosity:	1300 SSU (max)
Discharge Pressure:	70 psig (max)
Vacuum Chamber Operating VAC:	24" Hg \pm 2" Hg
Inlet Pressure:	+20 psig (max)
Inlet Pressure:	-10" Hg (min)
Power Requirements:	120 Volts, 15 Amps, 60 Hz, 1 Phase 20 kw max. connected load
Dimensions:	34" H x 27 1/2" W x 34" L (max)

3.4 PUMP TESTS

Pump Test 35 and 36 were conducted according to the test plans in Section 3.1. The pump tests were carried out at the in-house test facility in the Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base. The test circuit (see Fig. 1) consisted of a drive motor, a throttling valve, heat exchanger, reservoir, 5 micron filters and other accessories. Various flow, pressure and temperature sensors were used to monitor the test parameters. A torque sensor was mounted between the drive motor and the test pump. The stand was equipped with computerized data acquisition and control system, with automatic safety interlocks. Data obtained during the tests were also recorded on strip charts. The case drain flow was circulated through the reservoir, to ensure thorough mixing of all the test fluid.

A new or rebuilt pump was used for each test. The throttling valve was used to cycle the main flow rate between 12.5 gpm and 3 gpm, every minute. Fluid samples were drawn from the sampling port. A total of 8 gallons of fluid was initially placed in the stand, and no new fluid was added during the tests.

3.4.1 PUMP TEST WITH FRESH MIL-H-5606 (Test 35)

The base line test was completed successfully. At 946 hours, the throttling valve stuck in the maximum flow cycle (12.5 gpm) and the test continued until 972 hours. The test was stopped to fix the problem, and to inspect the pump. The pictures taken before the test, after 972 hours and after the completion of the 1500 hours are shown in Appendix-A. Polishing wear was observed on most of the pump parts except on the cylinder block face, on the piston shoe faces and on the main shaft end that mates with the needle bearing. Some erosion was observed around the kidney ports, on the cylinder block face and on the piston shoe faces. The main shaft, that acts as the inner race for the needle bearing, showed considerable spalling possibly due to the cyclic forces at the roller bearing/shaft interface. It was decided to continue the test without replacing any parts. No degradation in the pump performance was

observed due to the spalled shaft or the erosion on cylinder block and piston shoe faces. The 1500 hour inspection showed an increase in the erosion around the kidney ports on the cylinder block face and on the piston shoe faces. The spalling on the shaft did not seem to increase.

3.4.2 PUMP TEST WITH PURIFIED MIL-H-5606 (Test 36)

The pump test with purified fluid was completed successfully as planned. In order to subject this test to the same kind of conditions as experienced in Test 35, the throttling valve was set in the full flow condition at 946 hours. From 946 hours to 972 hours, the test was continued at a pump outlet flow of 12.5 gpm. The test was stopped at 972 hours, to inspect the pump. The pictures taken before the test, after 972 hours and after the completion of the 1500 hours are shown in the Appendix-B. Polishing wear was observed on most of the pump parts except that there was some erosion on the cylinder block face and on piston shoe faces. No degradation in the pump performance was observed due to the erosion on the cylinder block and on the piston shoe faces. The 1500 hour inspection showed an increase in the erosion around the kidney ports on the cylinder block face and on the piston shoe faces. The erosion on the piston shoe faces was somewhat more in this test than observed in Test 35.

The case drain flow in both tests increased rapidly first, and then almost leveled off. An increase in the case drain flow is generally attributed to increased pump wear, but that is not true for these tests. A comparison of the case drain flow and the fluid viscosity showed an inverse relationship (see Figs 3 and 4). Due to shearing of the VI (viscosity index) improver in MIL-H-5606, the fluid viscosity dropped rapidly, thereby causing an increased case drain flow. Once the fluid viscosity leveled off, so did the case drain flow. The pumps performed well in both tests in spite of a big reduction in fluid viscosity.

4.0 TEST RESULTS

4.1 ANALYSES OF FLUID SAMPLES

A number of fluid samples were analyzed for the following:

1. Viscosity
2. Acid Number
3. Water Content
4. Lubricity (4 Ball Wear Test)
5. Metal Content
6. Foaming

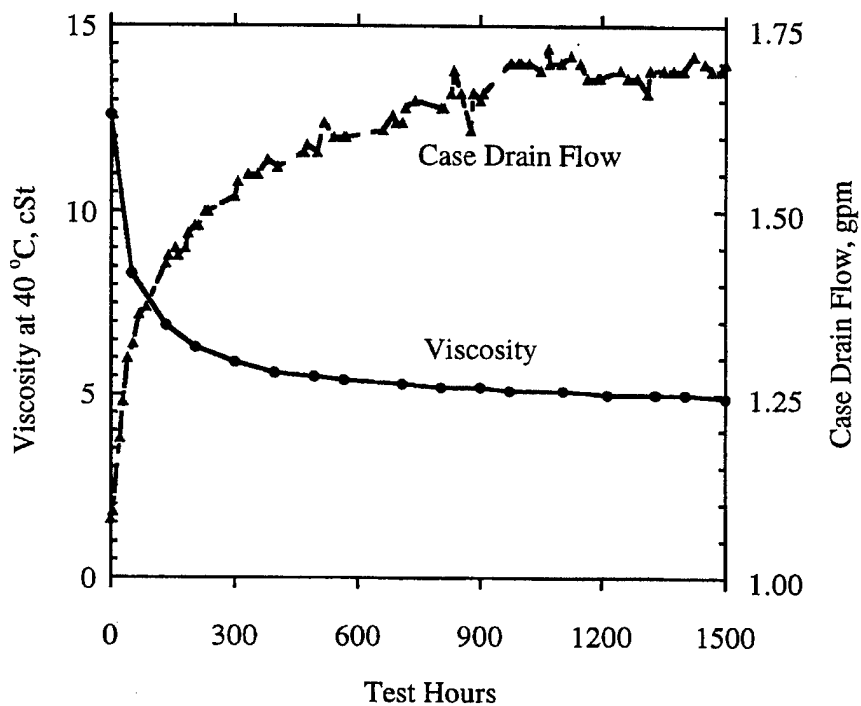


Figure 3. Case Drain Flow and Viscosity for Test 35 with Fresh Mil-H-5606

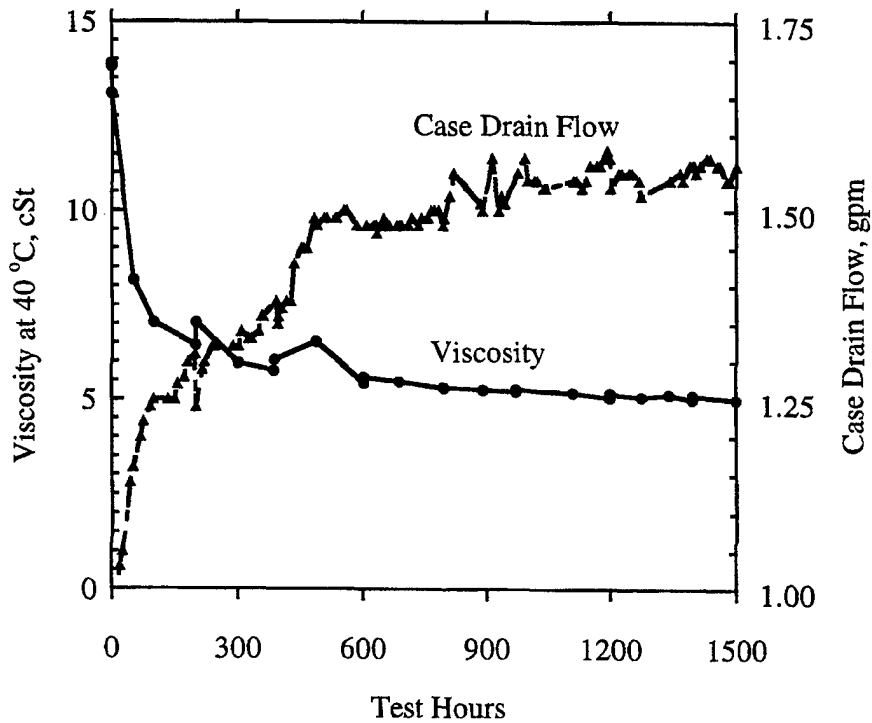


Figure 4. Case Drain Flow and Viscosity for Test 36 with purified Mil-H-5606

4.1.1 PERFORMANCE DIFFERENCES

The tests were performed to determine differences, if any, in the functioning of the fluid caused by the PALL purifier. It was assumed the purifiers do effectively clean the fluid as this has been demonstrated in other purifier tests. Areas of concern were in possible removal of the antiwear additive, tricresylphosphate, and in possible increase in foaming tendency caused by either removal of antifoam additives or the shearing of the viscosity index improver. During the pump tests, fluid samples were extracted from the operating test stand as the testing progressed. These samples were taken at the approximate intervals listed in Section 3.1. A number of different analyses were conducted on these samples (see Tables 1 and 2).

In all cases, no performance difference was found in fluid samples from either test. The viscosity of the fluid samples taken was determined at 40 °C (see Figures 3 and 4). It is easily seen that MIL-H-5606 suffered significant viscosity losses during the first 30 hours of pump testing, but a similar amount in both tests. The viscosity index (VI) improvers used to boost the viscosity of MIL-H-5606 break up under the high shear environment inside the pump and the throttling valve, causing a permanent loss of the fluid viscosity. Under the high pressure and high shear rate environment, the VI improved fluids behave more like the base oil [4].

Water content and acid numbers of the fluid samples were determined and are shown in Tables 1 and 2. Data are very similar.

A few samples of the baseline test and all samples taken during the purifier test were evaluated for lubricity by 4-ball wear testing ASTM Method D-4172. No differences were seen between the two pump tests.

Trace metal analysis was also performed on the fluid samples from the purifier pump test. The samples were analyzed for 19 elements including Fe, Ag, Cr, Cu, Mg, Na, Ni, Pb, Si, Sn, Ti, Ba, Cd, Mn, Mo, V, and Zn. Only those elements which show concentrations above 0.1 ppm. are reported in Table 2. No abnormalities were observed.

Foaming was measured in samples from the purifier test. No increase in foaming was observed.

Table 1. Fluid Characteristics - Samples From Test 35 With Fresh MIL-H-5606

MLO 95-	HOURS	Vis@40°C (cSt)	Acid Nr mgKOH/gm	KF Water (ppm)	Four-Ball	
					Run 1	Run 2
Specification limits		13.2 min	0.20	100 max	1.0 max	
196	0	12.6	0.02	74	0.98	1.04
197	50.1	8.3	a	a	a	a
198	133.1	6.9	a	a	a	a
199	205.0	6.3	a	a	a	a
220	300.9	5.9	a	a	a	a
221	396.8	5.6	a	a	a	a
222	493.4	5.5	a	a	a	a
223	566.1	5.4	a	a	a	a
224	708.9	5.3	a	a	a	a
228	804.7	5.2	a	a	a	a
229	900.7	5.2	0.03	74	0.90	0.88
230	972.4	5.1	a	a	a	a
231	1105.9	5.1	a	a	a	a
232	1214.0	5.0	a	a	a	a
233	1329.9	5.0	a	a	a	a
234	1401.3	5.0	a	a	a	a
96-1	1500.0	4.9	0.05	65	0.95	0.94

a = not determined

Table 2. Fluid Characteristics - Samples From Test 36 With Purified MIL-H-5606

MLO 96-	HOURS	Vis@40°C	KF Water	Acid #	Four-Ball		ICP (ppm)					
		(cSt)	(ppm)	mgKOH/gm	Run 1	Run 2	Fe	Zn	Cu	Pb	Ba	Na
Specification limits		13.2 min	100 max	a	1.0 max		N/A	N/A	a	a	N/A	N/A
20	Fresh	13.64	50	0.00	0.99,1.03	1.0	a	a	a	a	a	a
83	0.0	13.89	67	a	0.8	1.0	a	a	a	a	a	a
82	0.7	13.81	41	a	1.0	1.2	a	a	a	a	a	a
84	1.2	13.08	43	a	1.1	0.9	a	a	a	a	a	a
85	50.5	8.15	50	a	1.0	0.9	a	a	a	a	a	a
86	98.0	7.03	81	a	1.1	1.2	a	a	a	a	a	a
87	198.2	6.44	45	a	0.7	1.0	a	a	a	a	a	a
First Purification												
88	200.0	7.04	55	a	0.8	1.0	0.7	1.4	b	b	1.3	1.1
89	301.8	5.95	64	a	1.0	1.0	0.9	1.2	b	b	1.3	1.3
90	386.7	5.76	55	a	0.9	1.0	1.0	1.0	b	b	1.2	1.0
Second Purification												
91	386.7	6.05	70	a	1.0	1.0	1.0	1.4	b	b	1.4	1.6
92	486.7	6.53	58	a	1.0	0.9	a	a	b	b	a	a
93	603.2	5.44	a	a	1.0	0.8	1.3	1.6	b	b	1.3	0.2
Third Purification												
94	603.2	5.58	a	a	1.0	1.1	1.2	1.6	b	b	1.3	0.4
95	688.5	5.47	67, 60	a	1.0	1.1	1.2	1.4	b	b	1.2	2.3
96	796.3	5.30	a	a	0.7	0.7	1.3	1.6	b	b	1.3	2.8
Fourth Purification												
97	796.3	5.32	a	a	0.7	0.9	1.3	1.5	b	b	1.2	2.6
201	892.0	5.25	65, 69	a	0.7	0.9	1.2	1.6	b	b	1.2	2.5
202	972.0	5.21	a	a	0.7	0.9	1.2	1.7	b	b	1.1	1.2
Fifth Purification												
203	972.0	5.26	a	a	0.9	0.9	1.2	1.7	b	b	1.1	0.5
204	1110.8	5.18	a	0.00	0.9	1.0	1.1	1.5	b	b	0.9	0.8
205	1199.3	5.04	a	a	0.9	0.9	1.1	1.6	b	b	0.9	0.6
Sixth Purification												
206	1200.0	5.15	a	a	1.0	1.0	1.0	1.6	b	b	0.9	0.3
207	1274.4	5.06	a	0.00	0.7	0.7	1.0	1.5	b	b	0.9	0.5
208	1339.6	5.12	a	0.00	1.0	1.1	1.0	1.5	b	b	0.8	0.2
209	1394.8	4.97	a	a	0.9	1.0	1.0	1.5	0.2	0.7	0.9	0.8
Seventh Purification												
210	1395.3	5.09	a	a	0.8	0.7	1.0	1.6	0.2	0.4	0.9	0.8
211	1500.2	5.00	59	0.07	0.9	0.9	0.9	1.3	0.2	b	0.7	0.4

a = not determined

b = less than detection limits

5.0 CONCLUSIONS

5.1 Pump tests with both fresh and purified MIL-H-5606 fluids were successfully completed, and there was no apparent difference in pump performance with either fluid. In test with fresh MIL-H-5606, the main shaft that acts as the inner race for the needle bearing, showed considerable spalling. Polishing wear was observed on most of the pump parts except that there was some erosion on the cylinder block face and on piston shoe faces. The erosion on the piston shoe faces was somewhat more with the purified fluid than observed in the test with fresh MIL-H-5606. No degradation in the pump performance was observed due to shaft spalling or the erosion on cylinder block and piston shoe faces.

5.2 There was significant viscosity loss in both the fresh and the purified fluid tests. The reduction in viscosity with test time caused a corresponding increase in case drain flow. There was no significant change in the other fluid properties monitored.

Special Note: During the presentation on purifier testing of MIL-H-5606 hydraulic fluid at the SAE Committee A-6 meeting in Williamsburg, Virginia in April 1997, data were presented on the slightly increased erosion of metal from the faces of the bronze piston shoes with the purified fluid. At that meeting, a manufacturer's representative from both Vickers (Mr. Howard Sculthorpe) and Abex (Mr. Lyle Hibbs) remarked that the increased erosion may have been due to cavitation resulting from the purifier removing dissolved air from the hydraulic fluid. These manufacturers had both experienced increased cavitation erosion of the shoes when de-aerated hydraulic fluid was sent through hydraulic pumps. They felt this could have been the reason for the increased cavitation even though the hydraulic fluid in our pump tests sat overnight following purification prior to being put back into the test stand. We did not measure nor document the amount of dissolved air in the hydraulic fluid during these tests, either before or after purification, as this was not anticipated to be a parameter of interest at the time. While the increased cavitation experienced in the test using MIL-H-5606 did not cause an observable difference in pump operational parameters compared to the fresh MIL-H-5606 test, it may be worthwhile investigating the potential adverse effect of removing air from the hydraulic fluid with a fluid purifier. If it was determined that removal of air from the hydraulic fluid by purification resulted consistently in increased cavitation, it is not anticipated that this would result in the recommendation that purifiers not be used in the field. An additional step, either as a built-in feature that could be added to the fluid purifiers, or as an auxiliary process, that would re-aerate the hydraulic fluid before it was re-introduced into the airplane could be inserted into the technical orders covering the use of hydraulic fluid purifiers in the field. If, on the other hand, this increased cavitation was found to not correlate to the dissolved air in the fluid, but merely a condition that randomly occurs in hydraulic pumps, then the purifiers could be used without the need for any additional treatment of the hydraulic fluid before it is put back into the aircraft.

This information is important as more and more DoD bases are attempting to improve component lifetime and system performance by using fluid purifiers. While the use of purifiers

may extend the life of the hydraulic fluid (and reduce the waste stream of used fluid), this benefit must be weighed against possible lower hydraulic pump life due to increased cavitation erosion.

6.0 REFERENCES

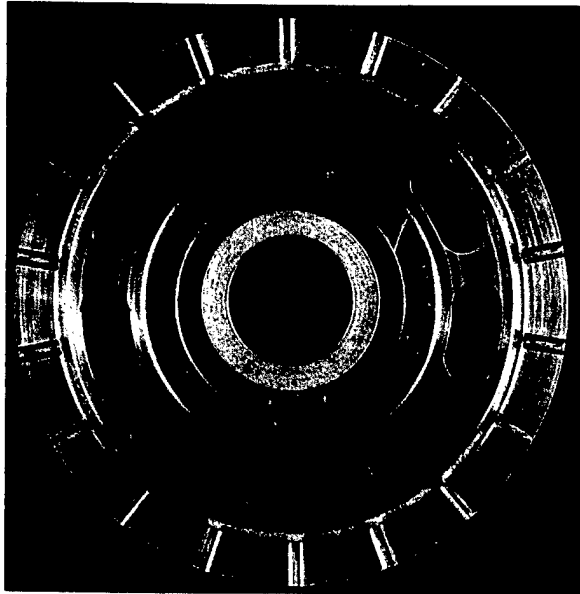
1. Snyder, C.E., Jr., Gschwender, L.J., and Schenach, T.A., "Recycling of MIL-H-5606 and MIL-H-6083 Mineral Based Hydraulic Fluids," Lubrication Engineering, **40**, 667-671 (1984).
2. Purdey, E. M., Rutkowski, D. M., and Sterting, F. D., "Recycling MIL-H-46170 Hydraulic Fluid to Extend Fluid Service Life," US Army, TARDEC Technical Report #13619, March 1995.
3. Gschwender, L. J., Snyder, C.E., Jr. and Sharma, S.K., "Pump Evaluation of Hydrogenated Polyalphaolefin Candidates for a -54°C to 135°C Fire-Resistant Air Force Aircraft Hydraulic Fluid," Lubrication Engineering, **44**, 4, 324-329 (1988).
4. Sharma, S.K. and Forster, N.H., and Gschwender, L.J., "Effect of Viscosity Index Improvers on the Elastohydrodynamic Lubrication Characteristics of a Chlorotrifluoroethylene and a Polyalphaolefin Fluid," Tribology Transactions, **36**, 3, pp 555-564, Oct 1993.

7.0 ACKNOWLEDGMENTS

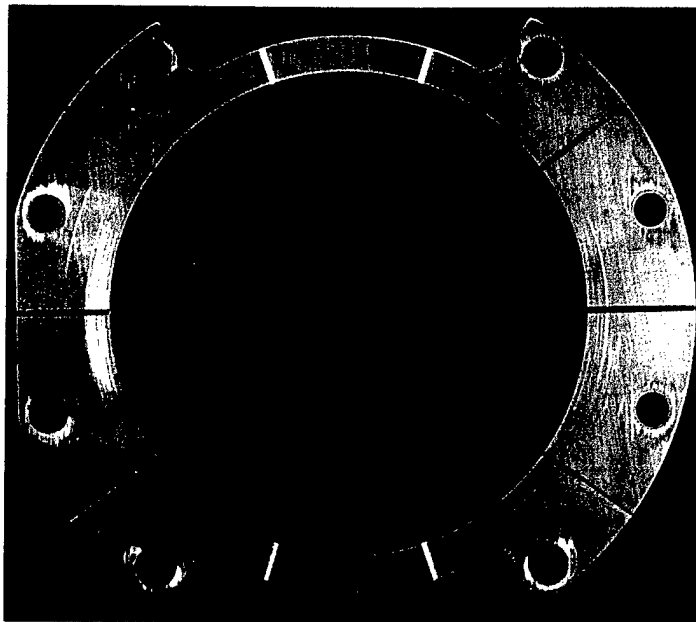
Funding for this project was made possible through the \$Aving thru Value Enhancement (\$AVE) Program. The Defense Logistics Agency (DLA) initiated and funded the \$Aving thru Value Enhancement (\$AVE) Program in Fiscal Year (FY) 1993 as a cost-saving method to improve reliability and maintainability (R&M) for DLA-managed items. This program provides funding for each military service (Army, Navy, Marine Corps, and Air Force) and their contractors to identify and correct DLA problematic items if they can validate and document a Value Engineering (VE)/R&M/ Breakout savings Return on Investment (ROI) of at least 10 to one. (Note: The ROI may accrue to either the military or DLA.) The DLA and the military will benefit from the cost savings achieved through enhanced competition and the productive use of available organic resources and military expertise. The Air Force's \$AVE Program is managed at Wright-Patterson AFB by Aeronautical System Command's Aging Aircraft and Systems Office, DSN 785-7210, or (937) 255-7210.

8.1 APPENDIX A

Photos from Pump Test with Fresh MIL-H-5606 (Test 35)

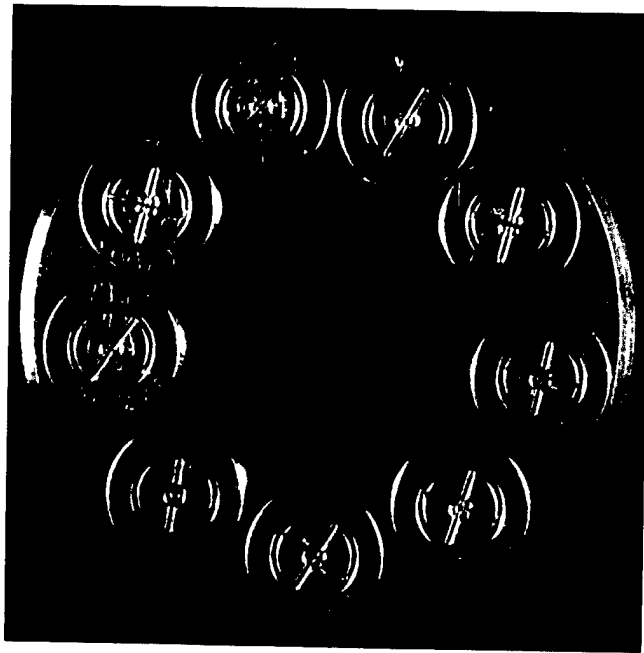


Cylinder Block Face

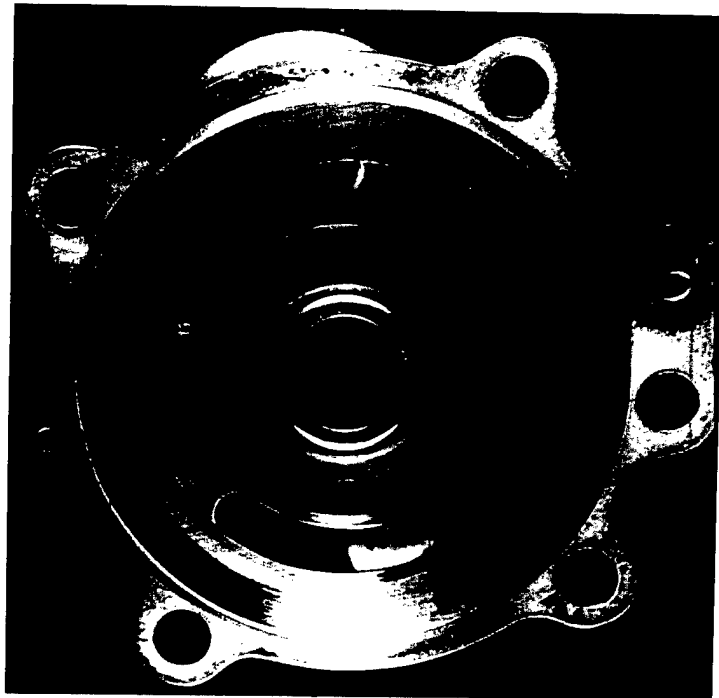


Hold Down Plate - Rubbing Side

Cylinder Block Face and Hold Down Plate - Rubbing Side at Pretest
Pump Test 35 with MIL-H-5606

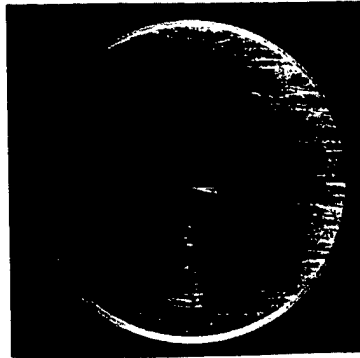


Piston Shoe Faces

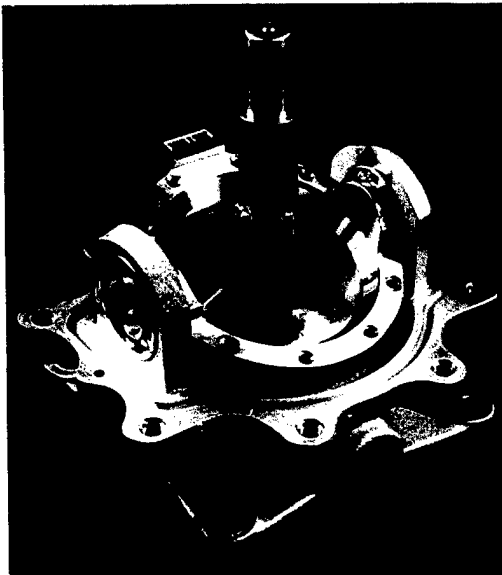


Valve Plate

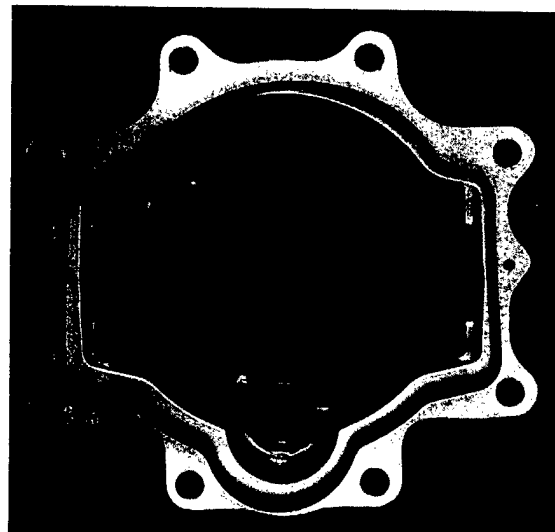
Piston Shoe Faces and Valve Plate at Pretest
Pump Test 35 with MIL-H-5606



Actuator Piston - Top View



Partial Pump Assembly

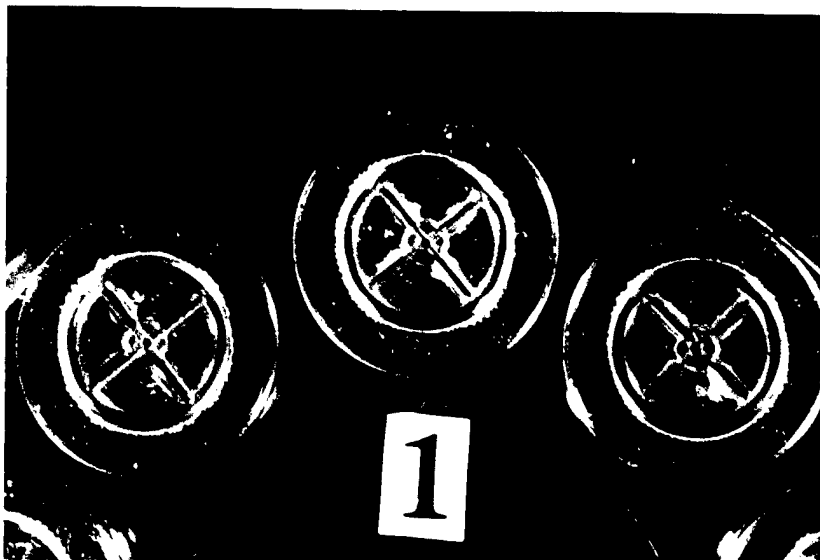


Housing

Actuator Piston - Top View, Housing, and Partial Pump Assembly at Pretest
Pump Test 35 with MIL-H-5606

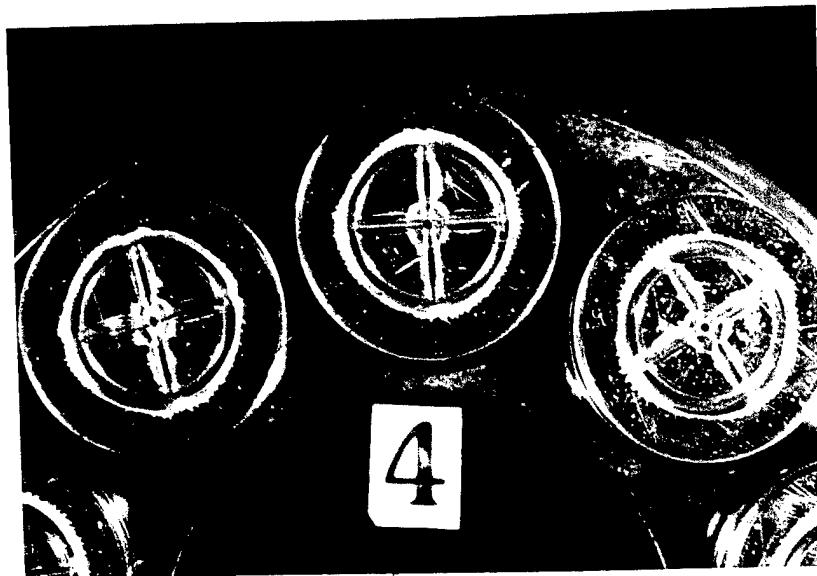


Piston Shoe Faces

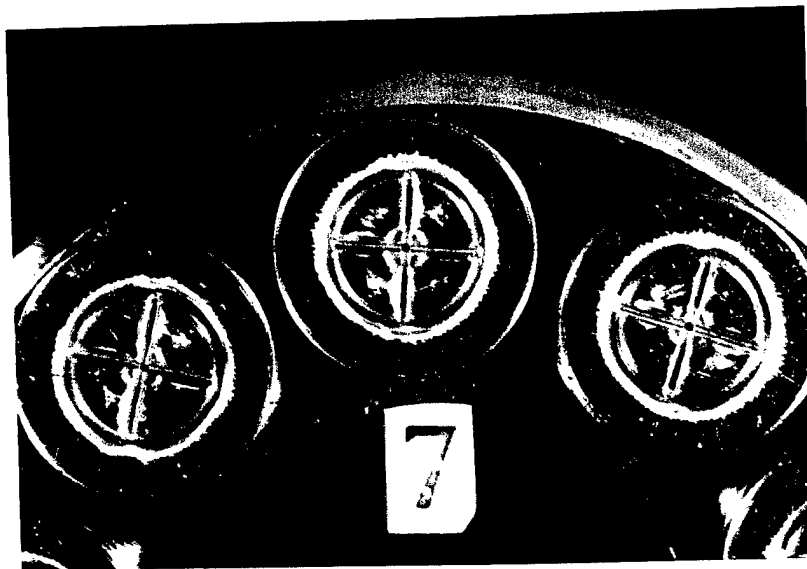


Enlargement of Piston Shoe Faces 9,1,2

Piston Shoe Faces after 972 Hours
Pump Test 35 with MIL-H-5606

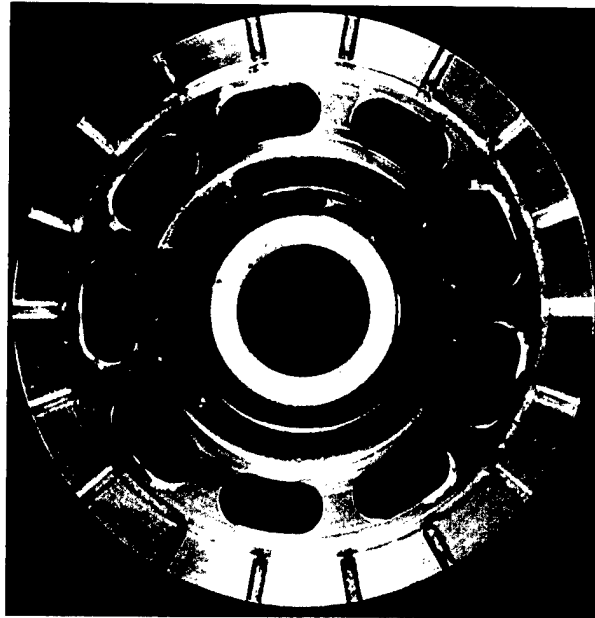


Enlargement of Piston Shoe Faces 3,4,5

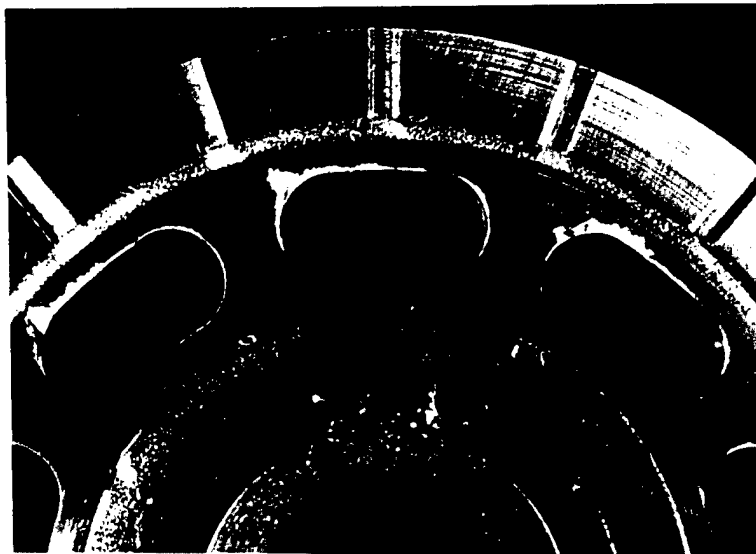


Enlargement of Piston Shoe Faces 6,7,8

Piston Shoe Faces after 972 Hours
Pump Test 35 with MIL-H-5606

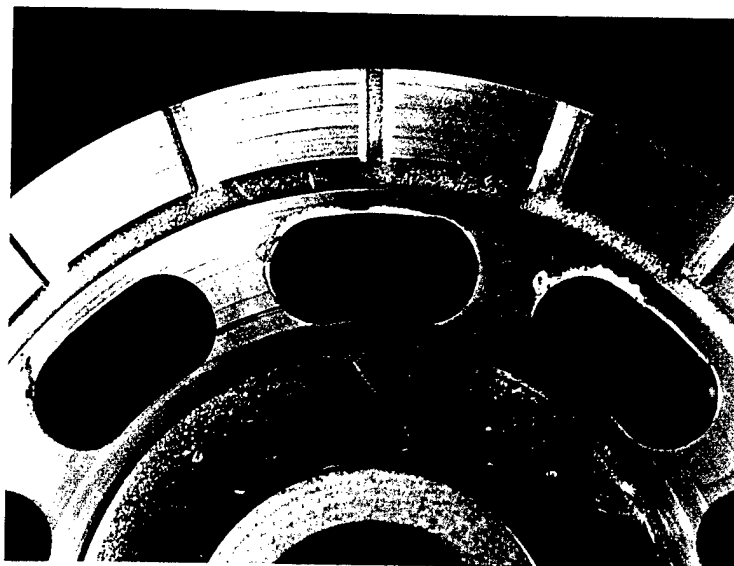


Cylinder Block Face

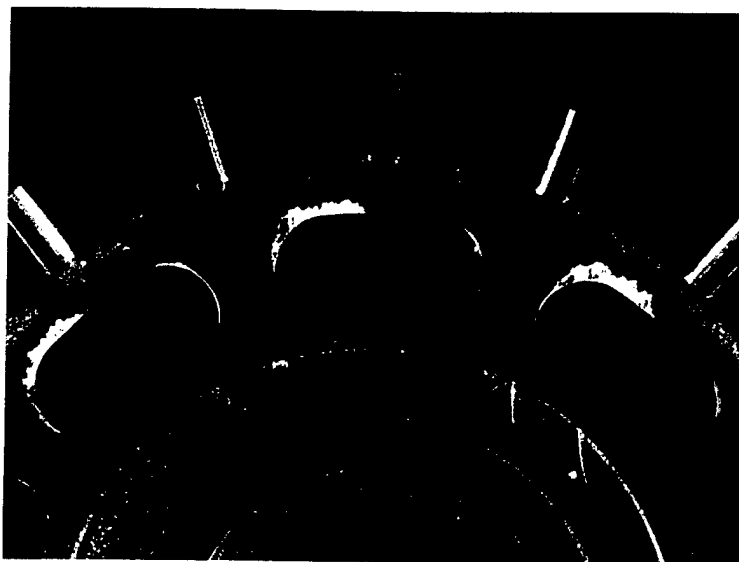


Enlargement of Cylinder Block Face

Cylinder Block Faces after 972 Hours
Pump Test 35 with MIL-H-5606



Enlargement of Cylinder Block Face



Enlargement of Cylinder Block Face

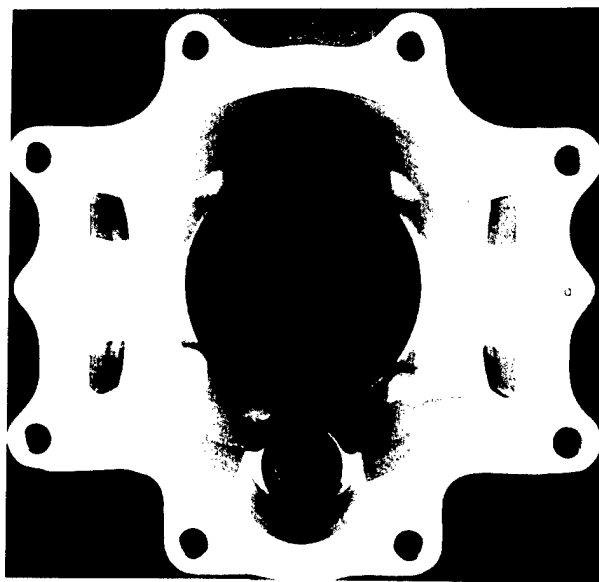
Cylinder Block Faces after 972 Hours
Pump Test 35 with MIL-H-5606



Actuator Piston - Top View

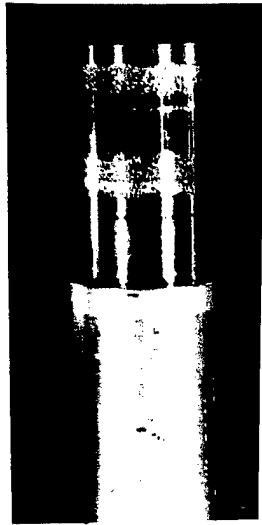


Partial Pump Assembly

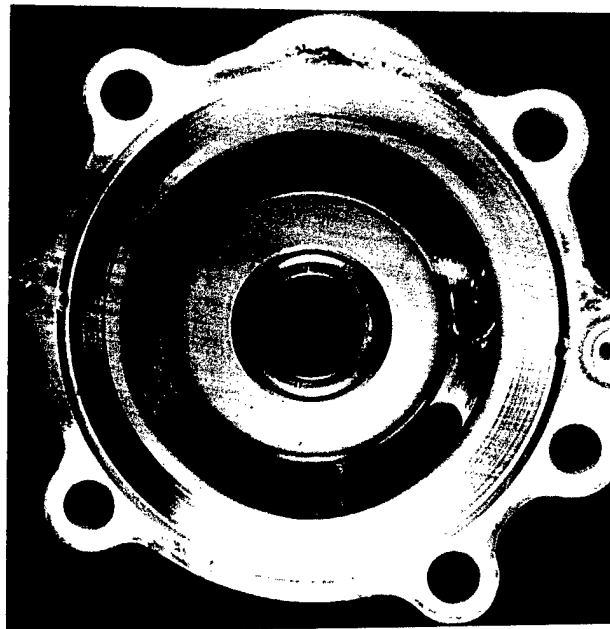


Housing

Actuator Piston - Top View, Housing, and Partial Pump Assembly after 972 Hours
Pump Test 35 with MIL-H-5606

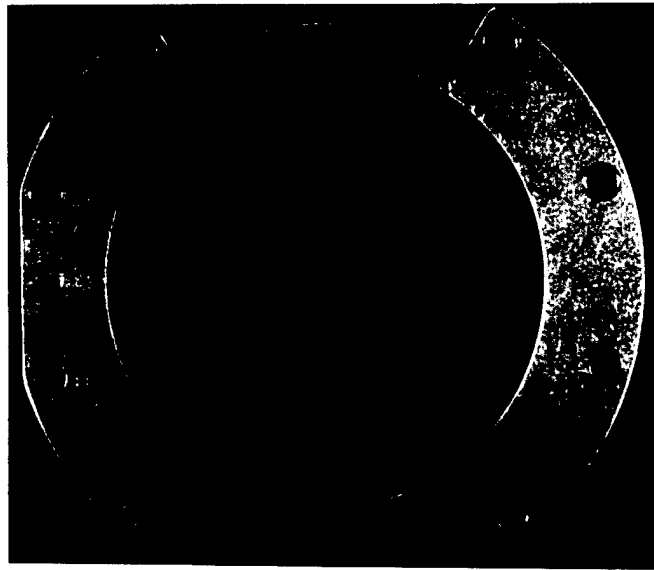


Pump Shaft

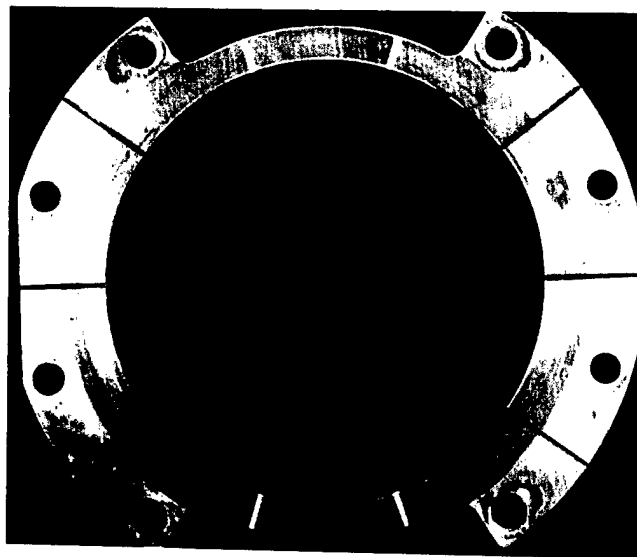


Valve Plate

Pump Shaft and Valve Plate after 972 Hours
Pump Test 35 with MIL-H-5606

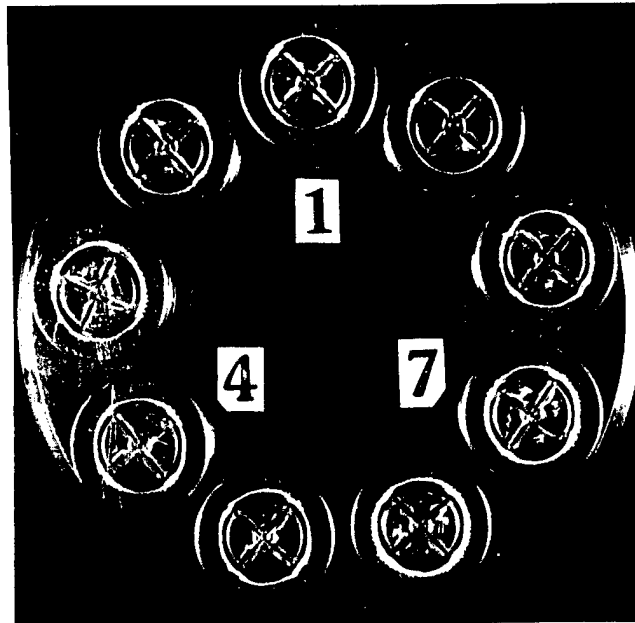


Hold Down Plate-Rubbing Side

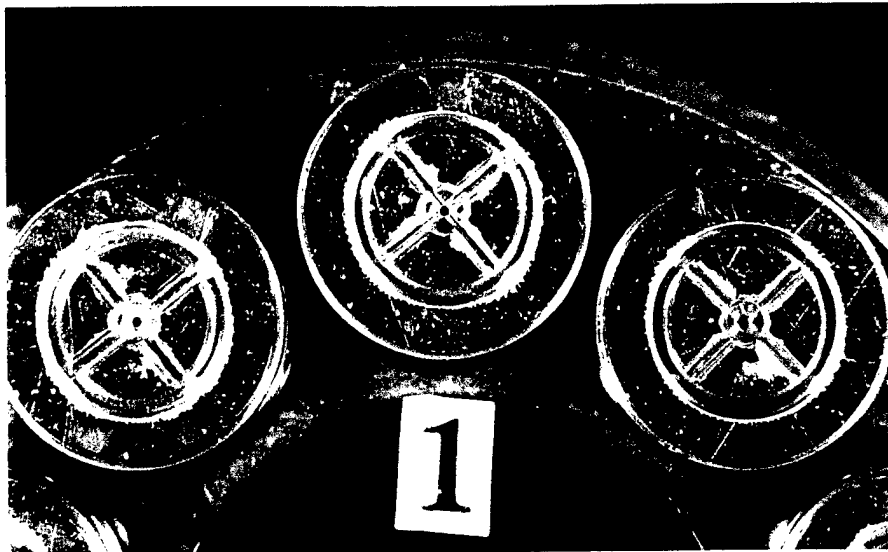


Hold Down Plate-Non Rubbing Side

Hold Down Plate after 972 Hours
Pump Test 35 with MIL-H-5606

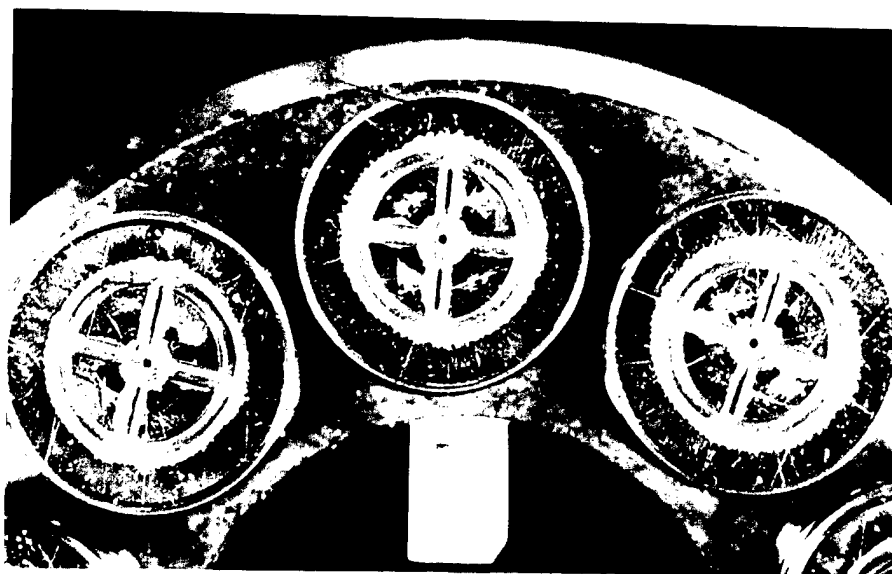


Piston Shoe Faces

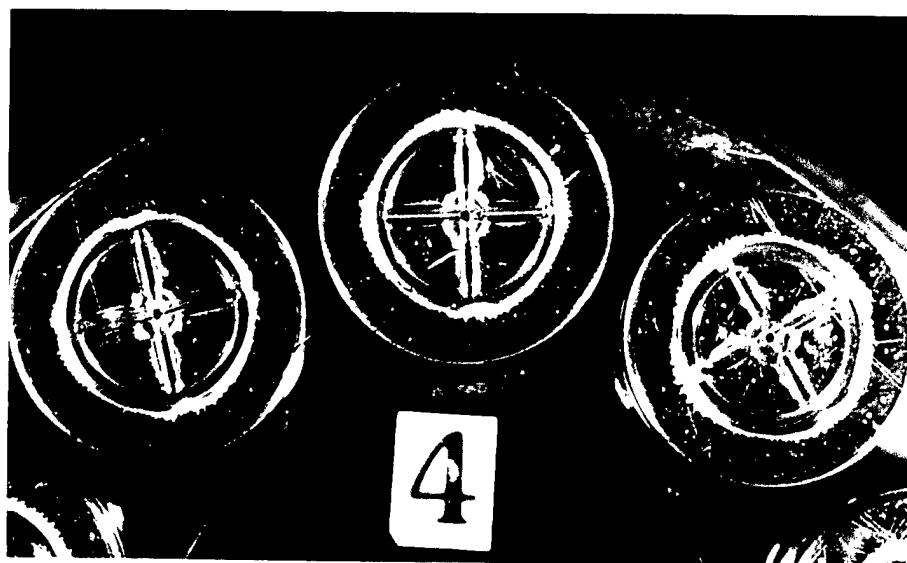


Enlargement of Piston Shoe Faces 9,1,2

Piston Shoe Faces after 1500 Hours
Pump Test 35 with MIL-H-5606

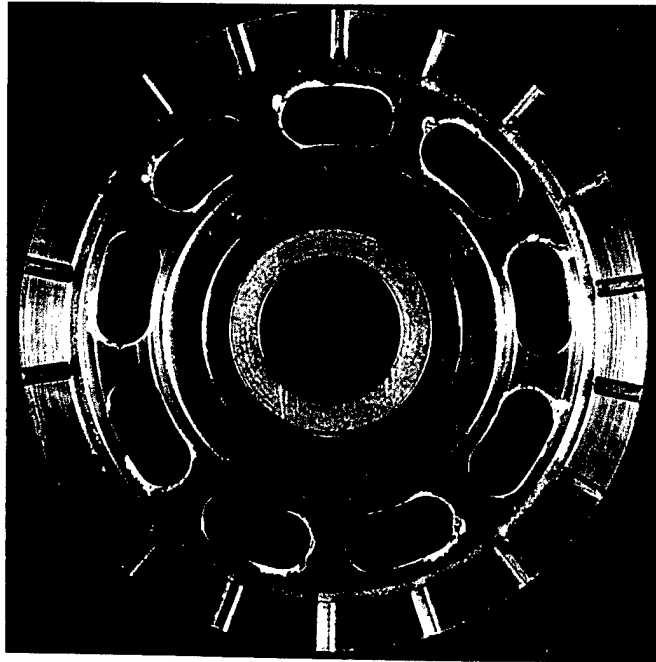


Enlargement of Piston Shoe Faces 6,7,8

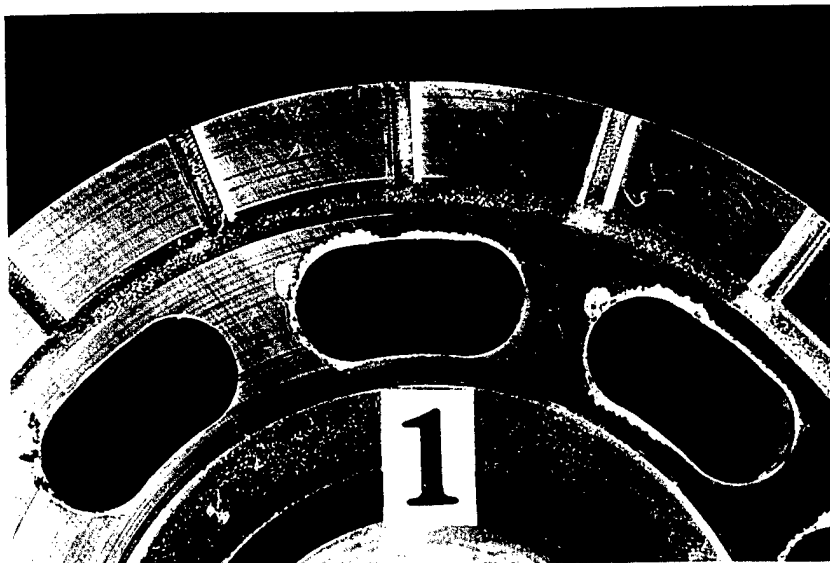


Enlargement of Piston Shoe Faces 3,4,5

Piston Shoe Faces after 1500 Hours
Pump Test 35 with MIL-H-5606

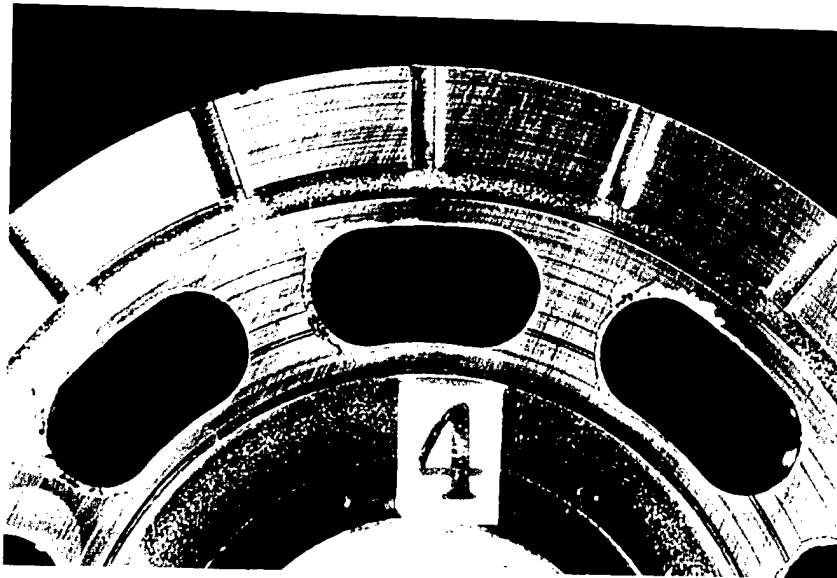


Cylinder Block Face



Enlargement of Cylinder Block Face

Cylinder Block Faces after 1500 Hours
Pump Test 35 with MIL-H-5606

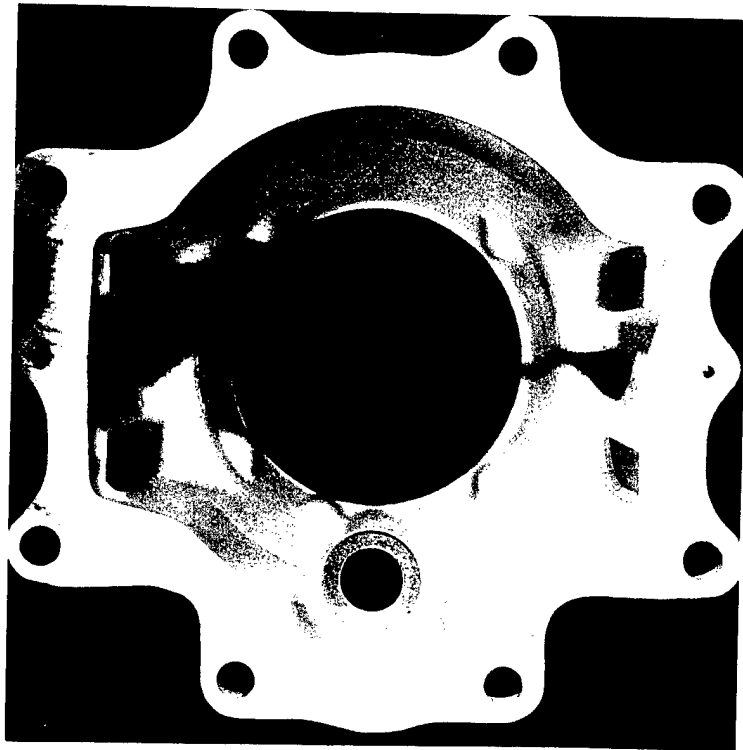


Enlargement of Cylinder Block Face

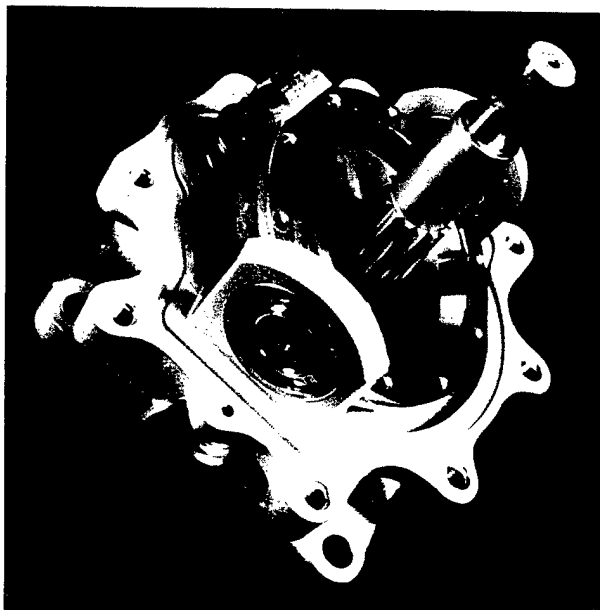


Enlargement of Cylinder Block Face

Cylinder Block Faces after 1500 Hours
Pump Test 35 with MIL-H-5606



Housing



Partial Pump Assembly

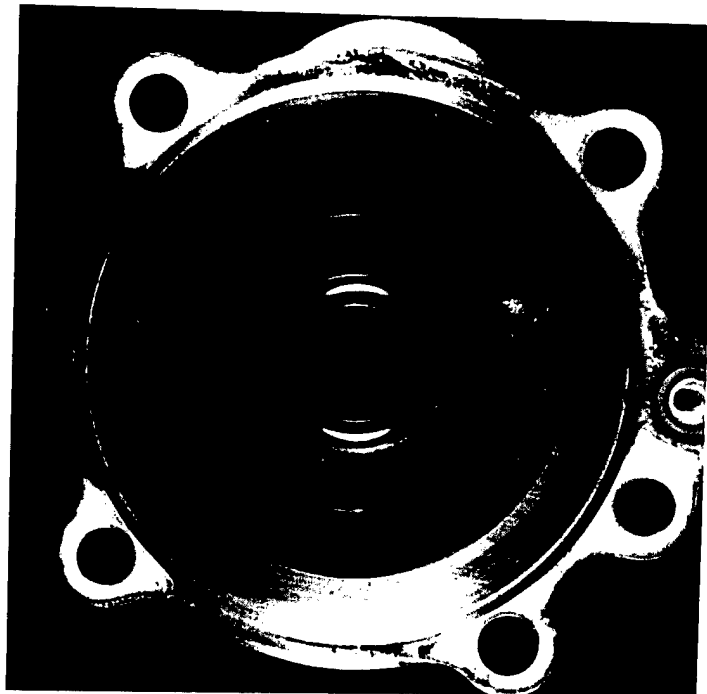


Actuator Piston - Top View

Actuator Piston - Top View, Housing, and Partial Pump Assembly after 972 Hours
Pump Test 35 with MIL-H-5606



Pump Shaft

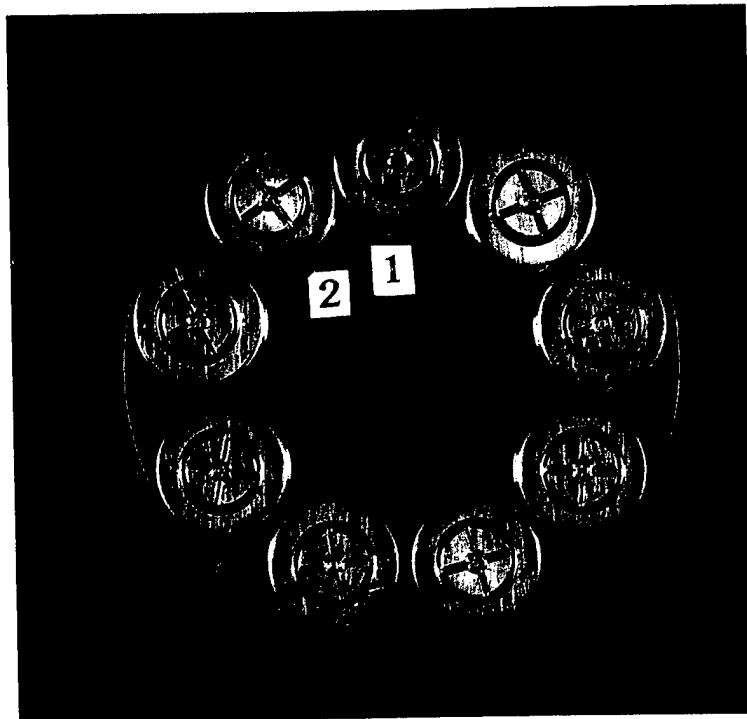


Valve Plate

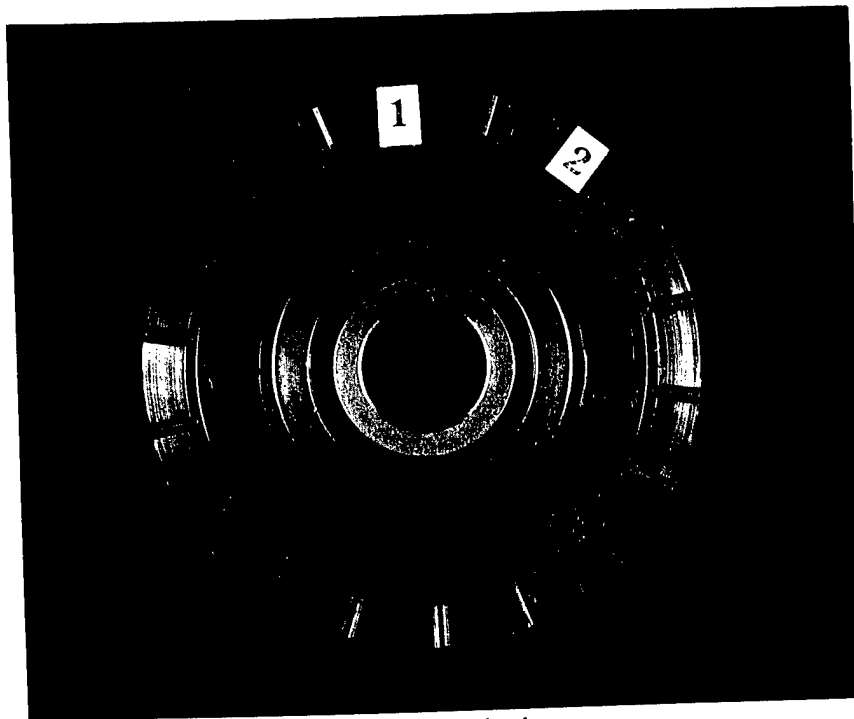
Cylinder Block Faces after 1500 Hours
Pump Test 35 with MIL-H-5606

8.2 APPENDIX B

Photos from Pump Test with Purified MIL-H-5606 (Test 36)

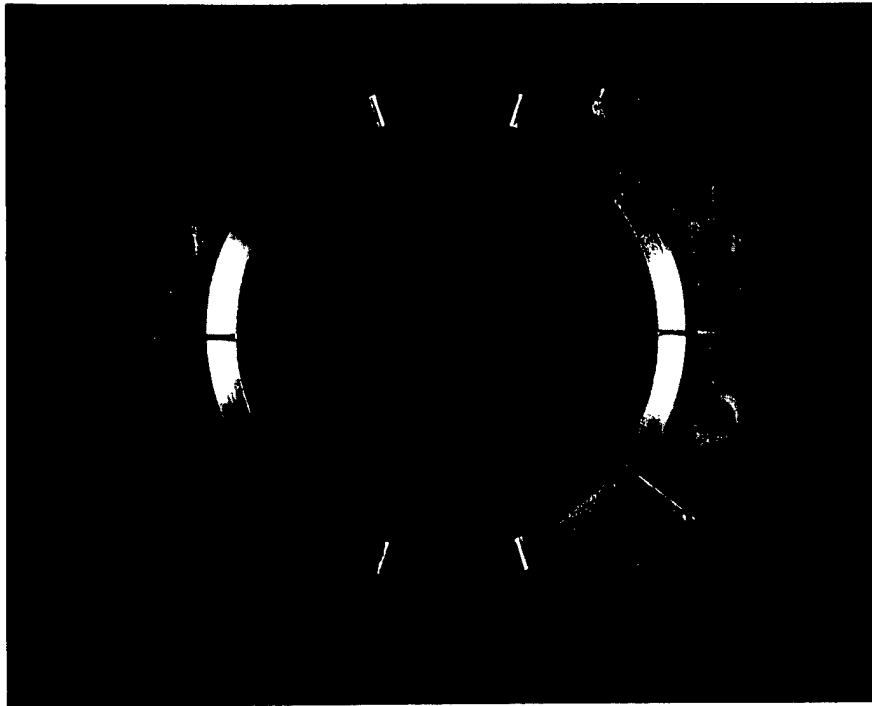


Piston Shoe Faces

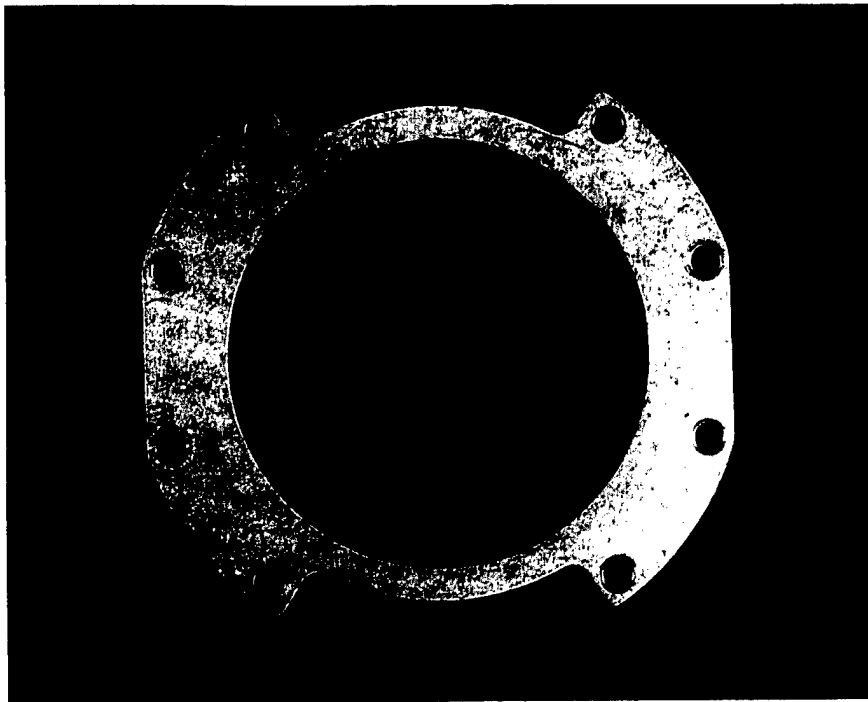


Cylinder Block

Piston Shoe Faces and Cylinder Block Faces at Pre-test
Pump Test 36 with MIL-H-5606

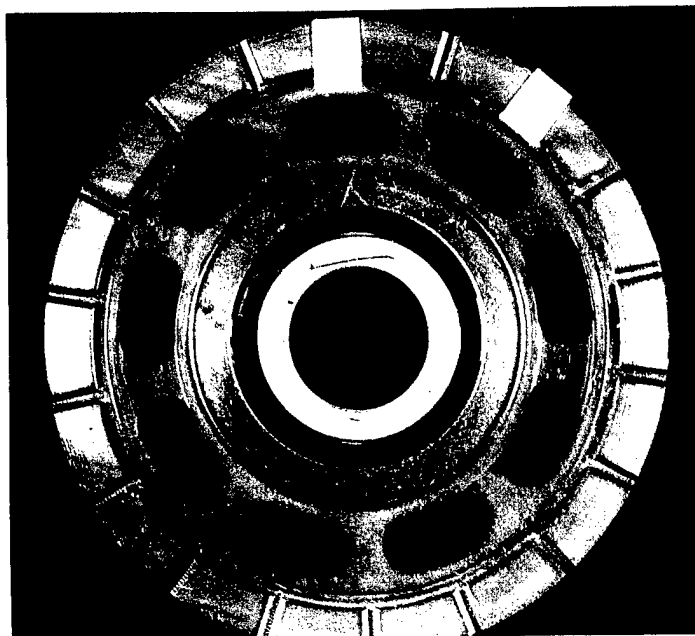


Rubbing Side

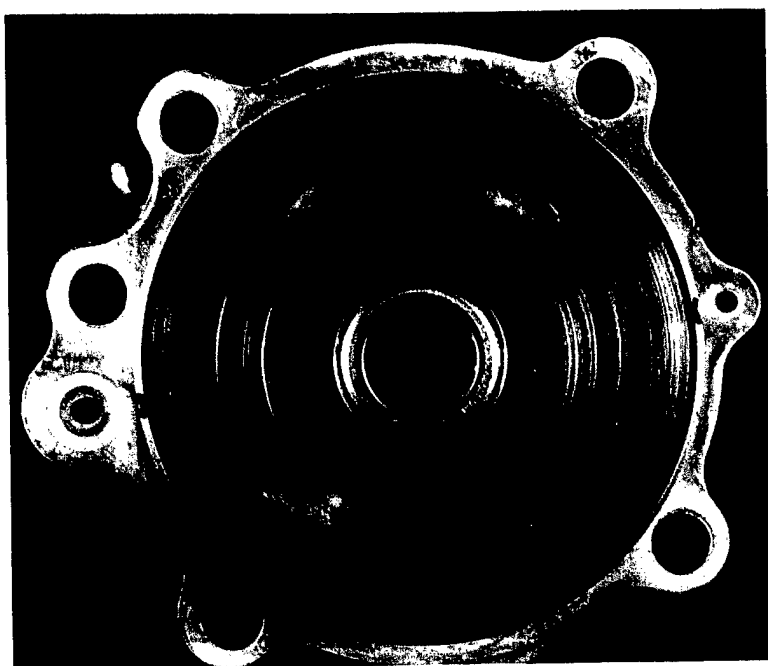


Non-Rubbing Side

Hold Down Plate at Pre-test
Pump Test 36 with MIL-H-5606

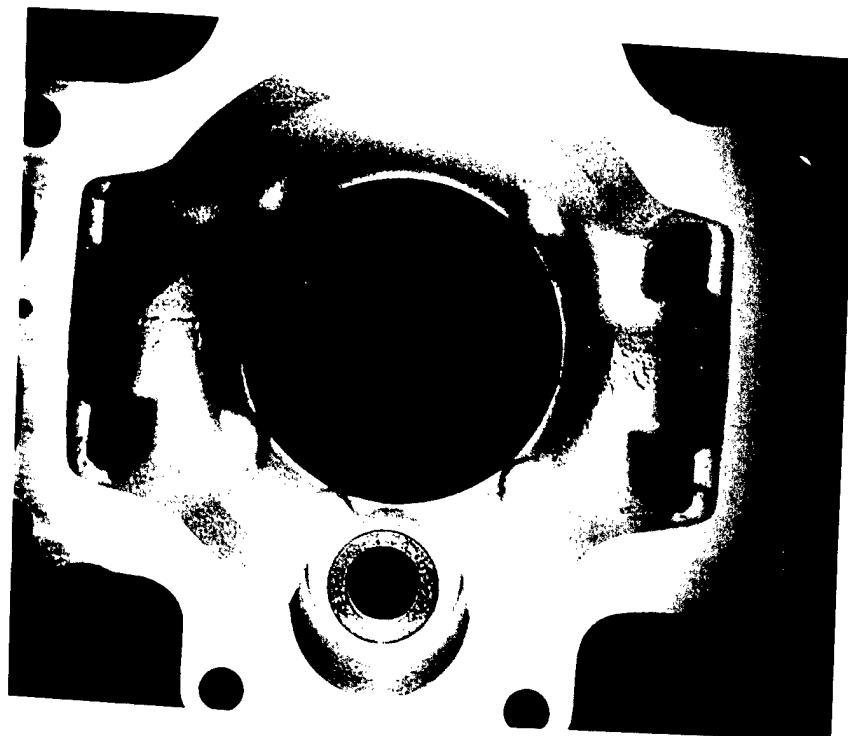


Cylinder Block Face

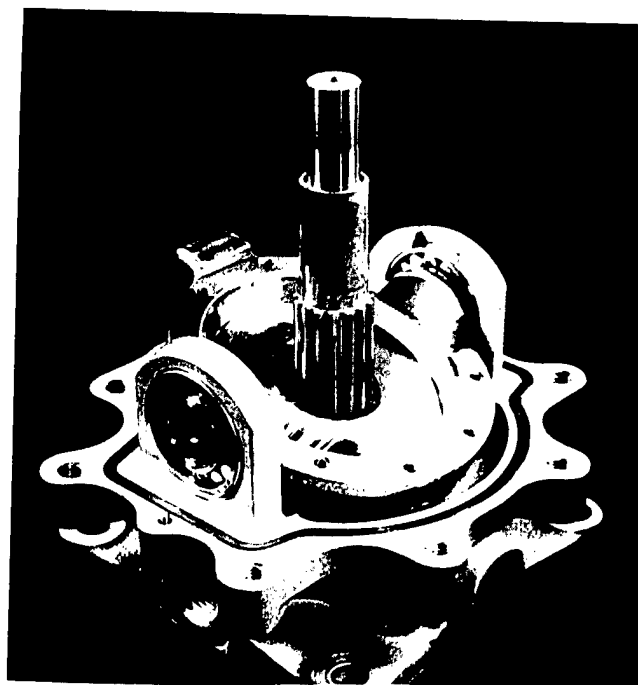


Cylinder Block Plate

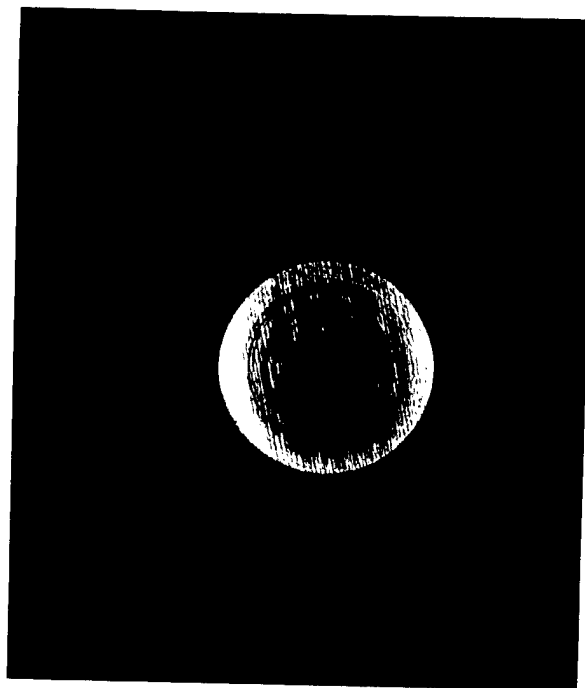
Cylinder Block Face and Plate after 972 hrs.
Pump Test 36 with MIL-H-5606



Housing

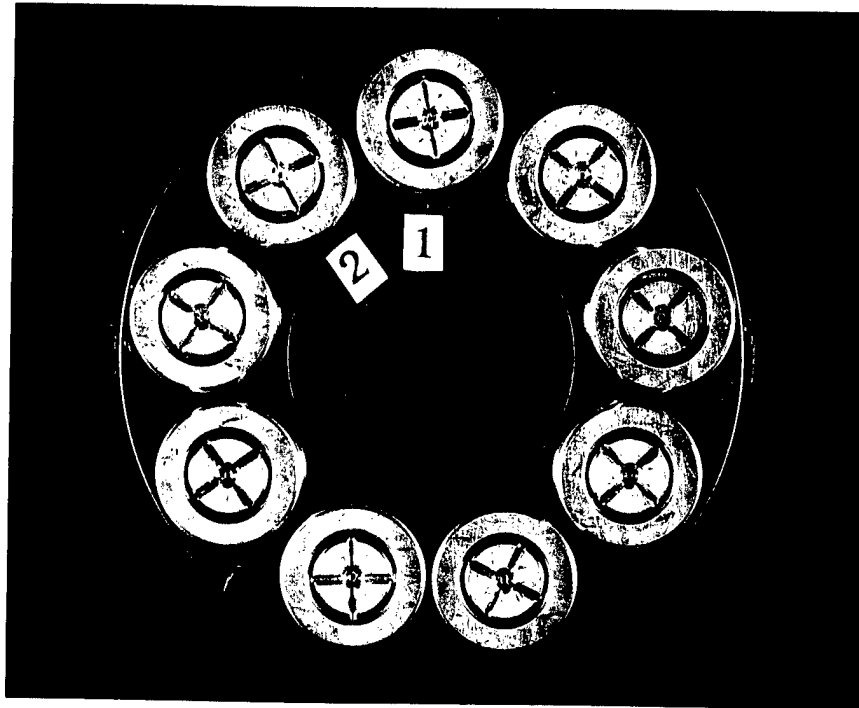


Partial Pump Assembly



Actuator Piston - Front View

Pump Components at Pre-test
Pump Test 36 with MIL-H-5606

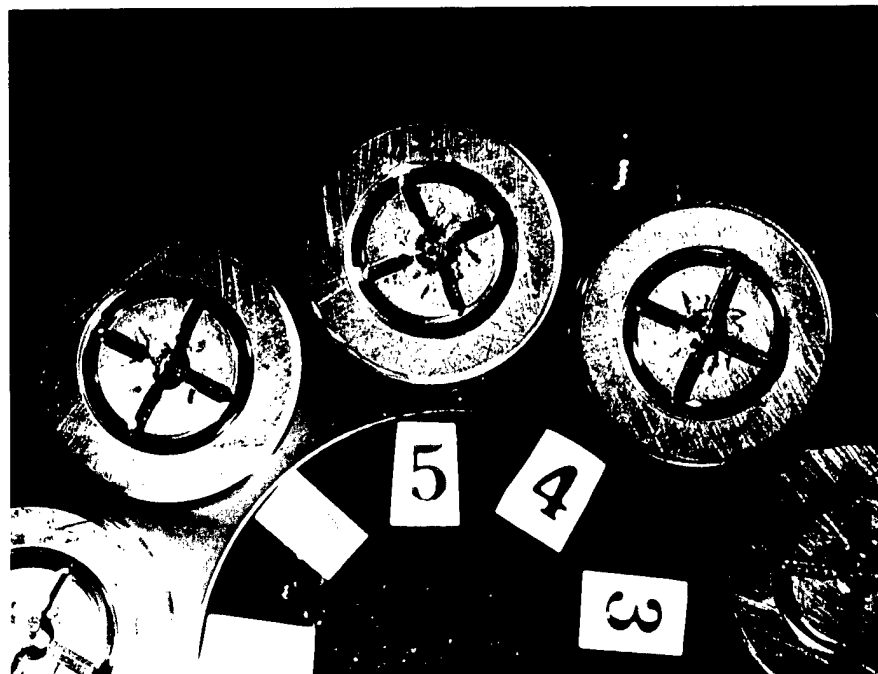


Piston Shoe Faces

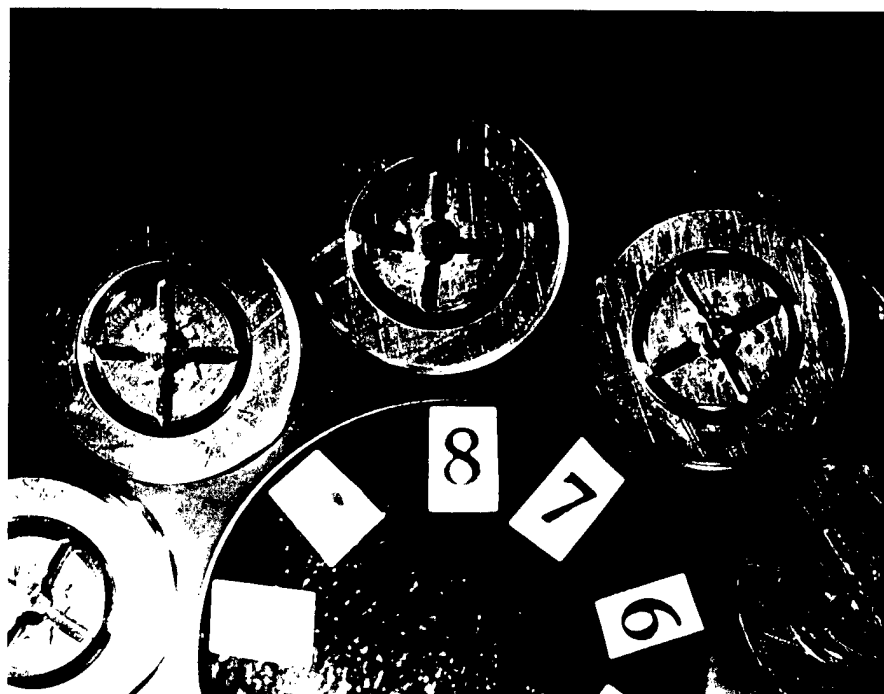


Piston Shoe Faces 1,2,3

Piston Shoe Faces after 972 hrs.
Pump Test 36 with MIL-H-5606

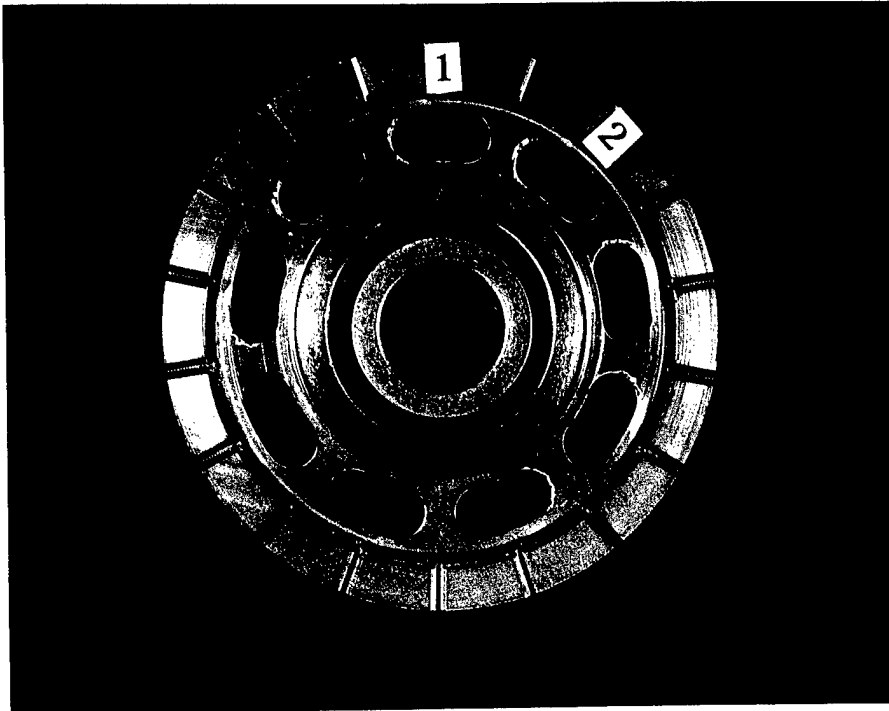


Piston Shoe Faces 4,5,6

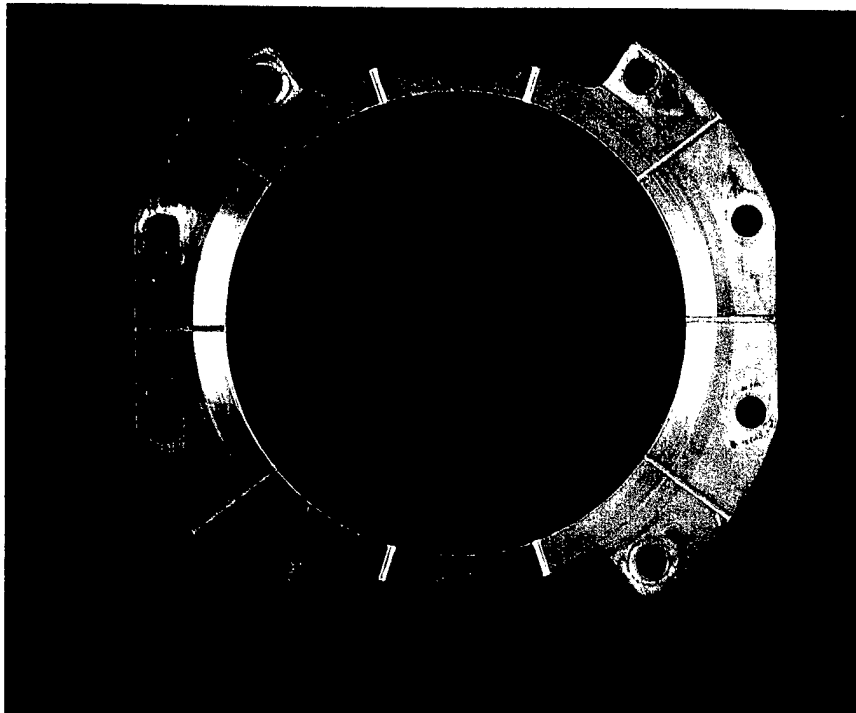


Piston Shoe Faces 7,8,9

Piston Shoe Faces after 972 hrs.
Pump Test 36 with MIL-H-5606

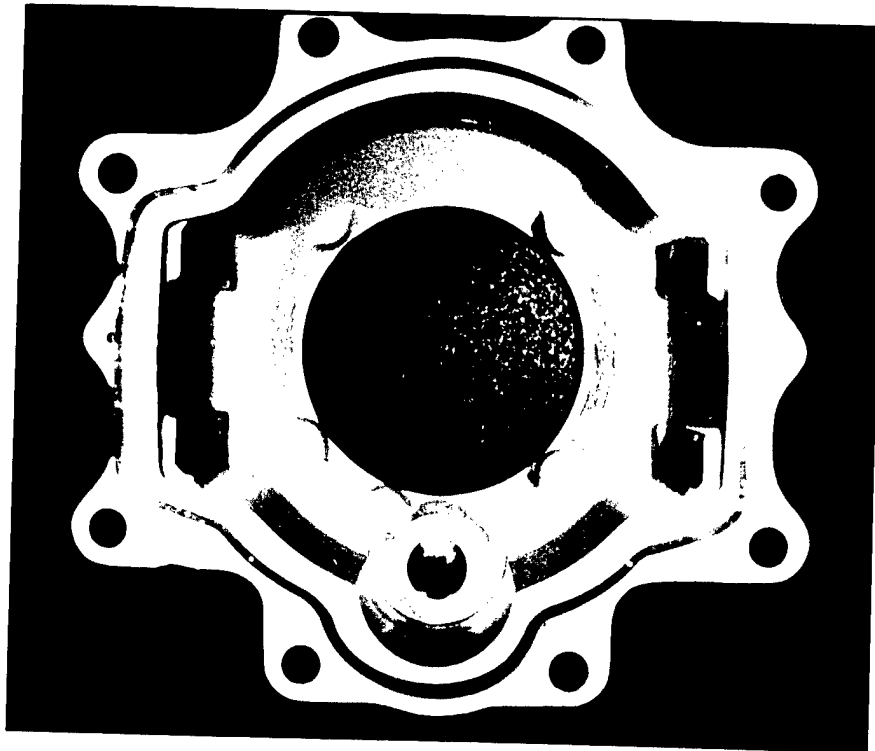


Cylinder Block Face

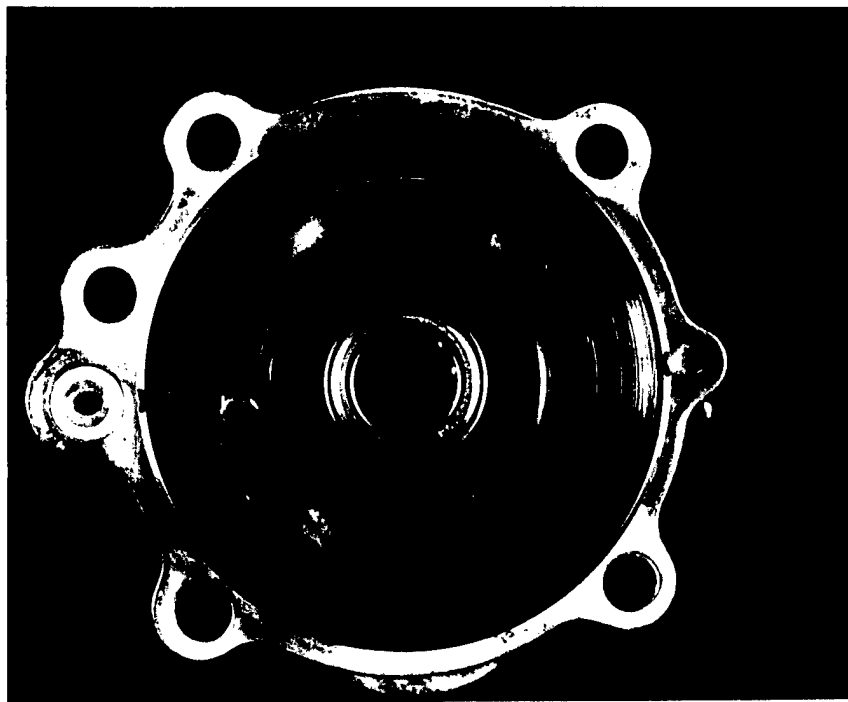


Hold Down Plate-Non-Rubbing Side

Cylinder Block Face and Plate after 972 hrs.
Pump Test 36 with MIL-H-5606



Housing

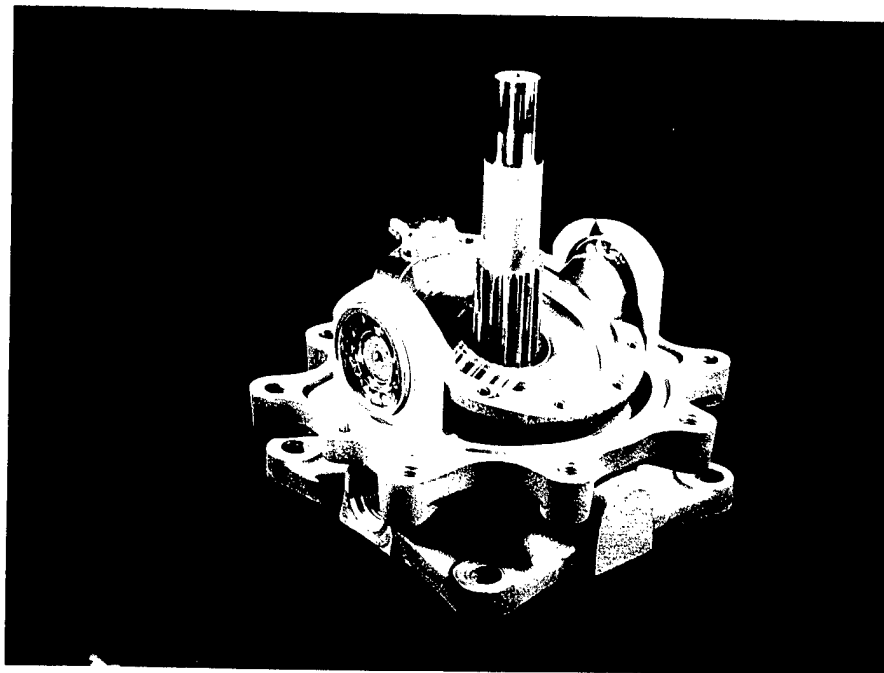


Cylinder Block Plate

Housing and Cylinder Block Plate after 972 hrs.
Pump Test 36 with MIL-H-5606

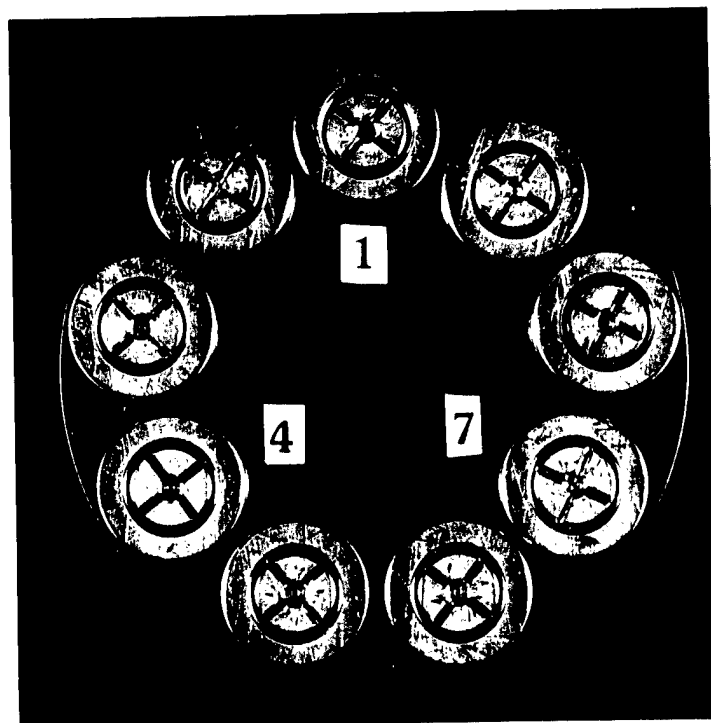


Actuator Piston-Front View



Partial Assembly of Test Pump

Actuator Piston and Partial Assembly after 972 hrs.
Pump Test 36 with MIL-H-5606

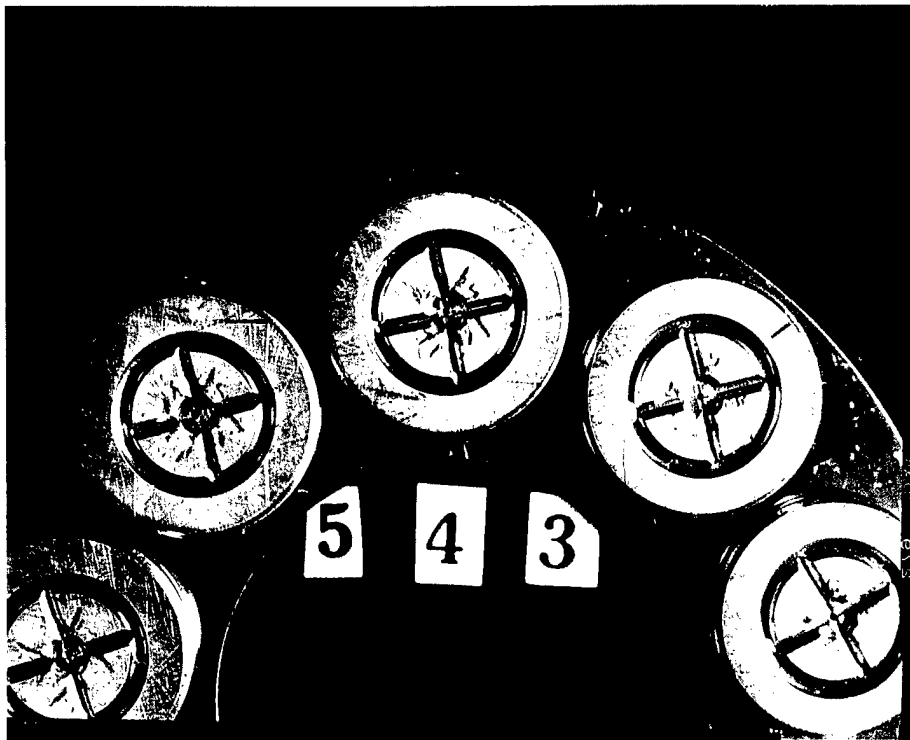


Piston Shoe Faces

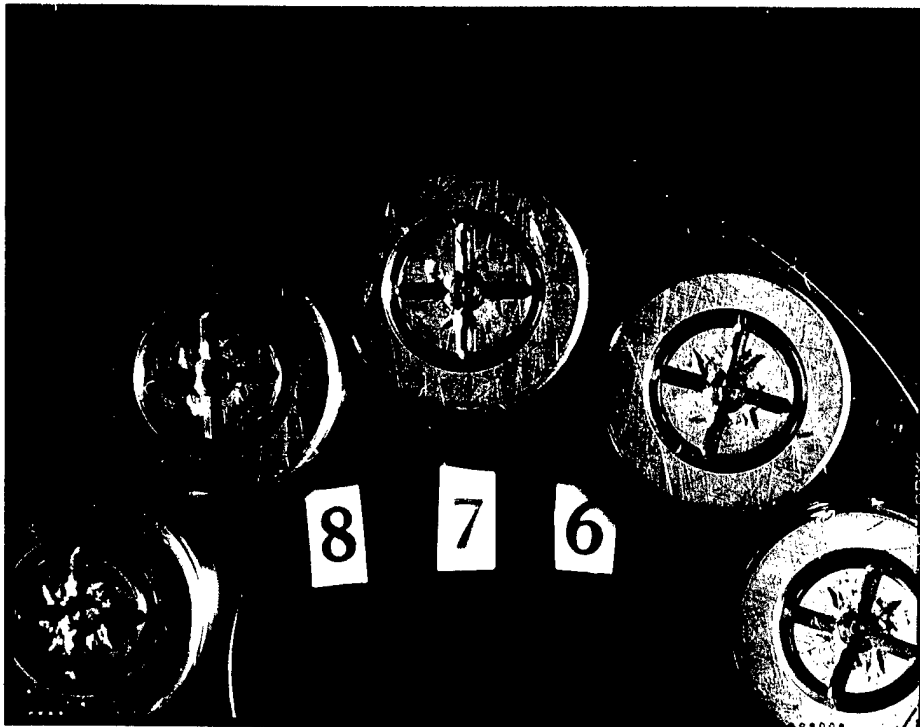


Piston Shoe Faces 2,1,9

Piston Shoe Faces after 1500 hrs.
Pump Test 36 with MIL-H-5606

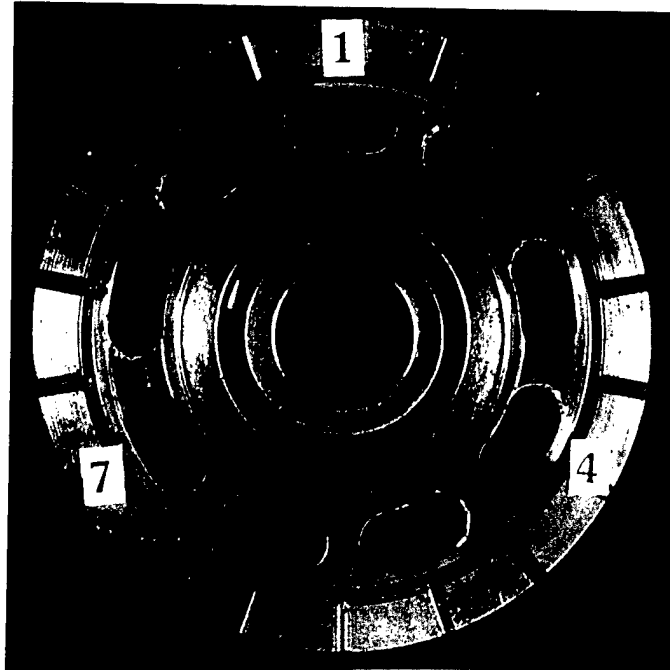


Piston Shoe Faces 3,4,5

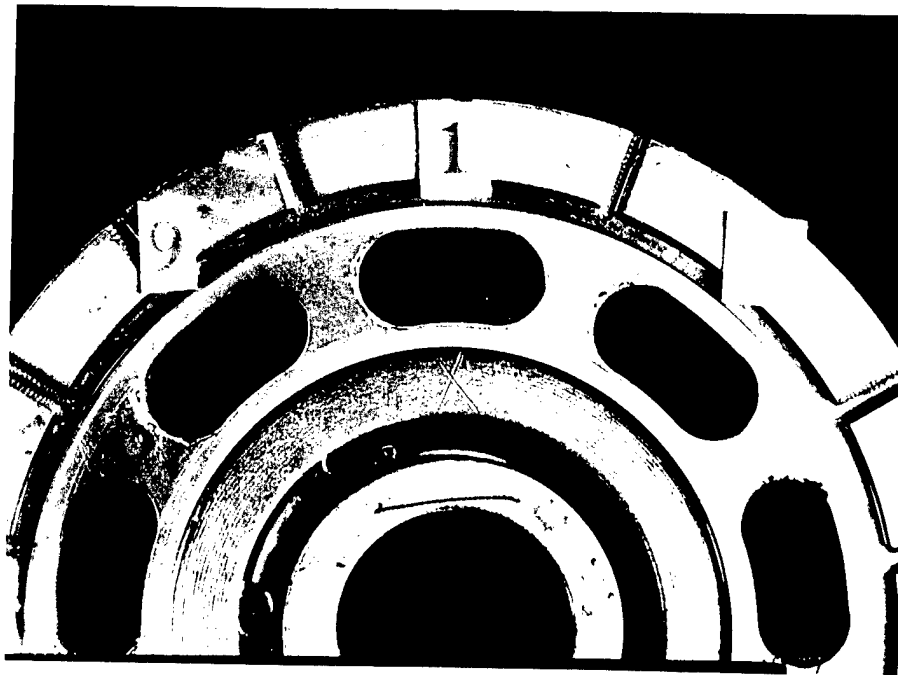


Piston Shoe Faces 6,7,8

Piston Shoe Faces after 1500 hrs.
Pump Test 36 with MIL-H-5606

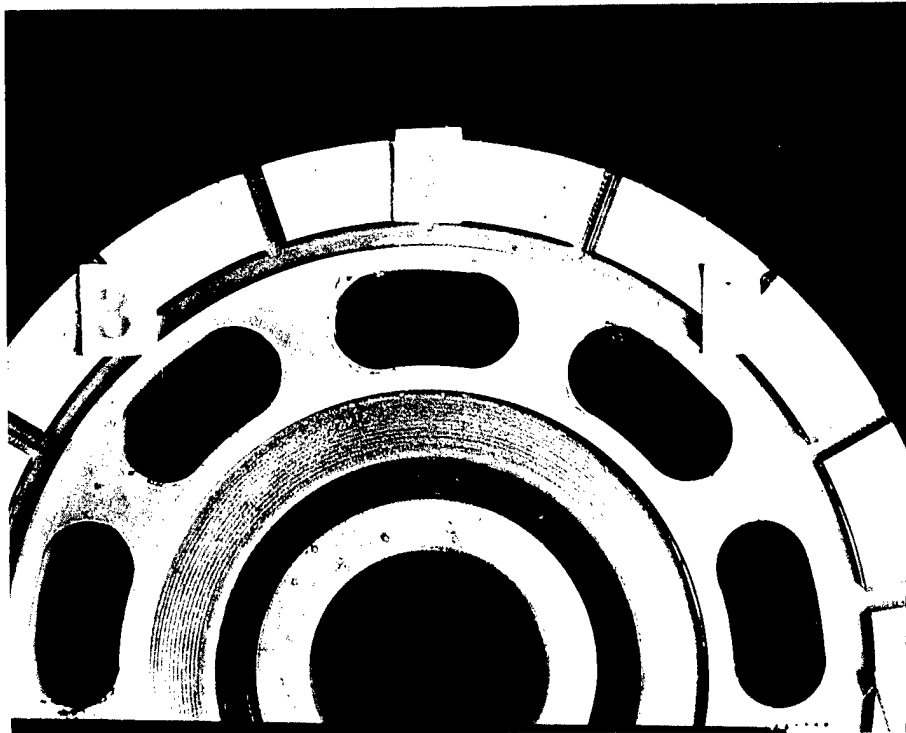


Cylinder Block Face

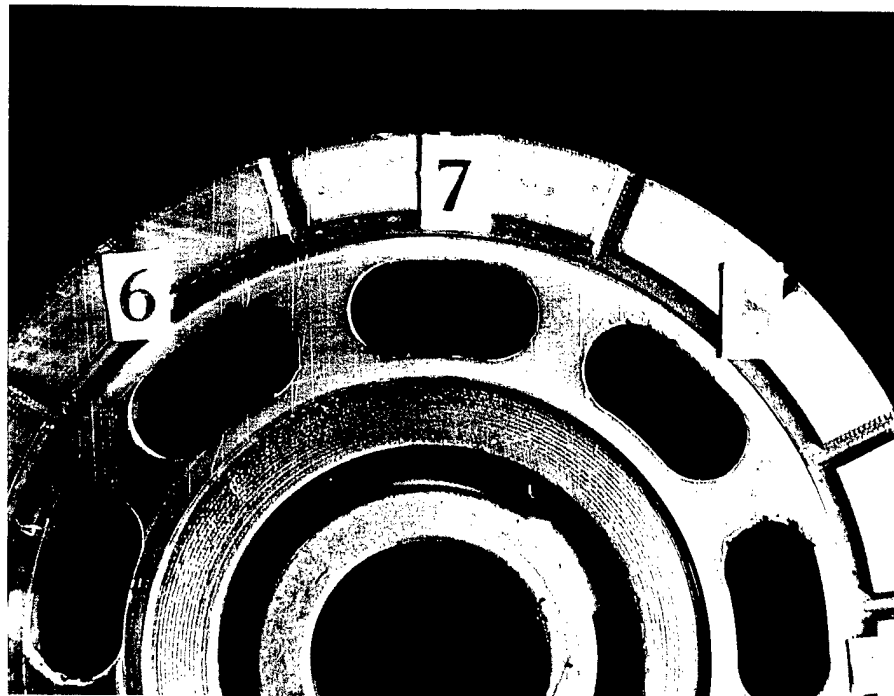


Cylinder Block Face 9,1,2

Cylinder Block Face after 1500 hrs.
Pump Test 36 with MIL-H-5606

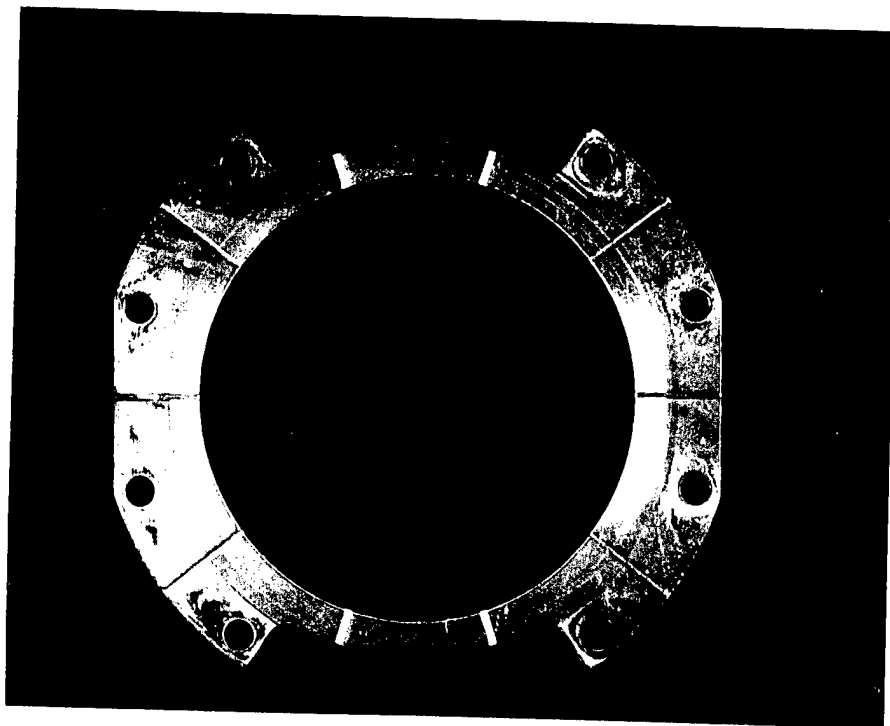


Cylinder Block Face 3,4,5

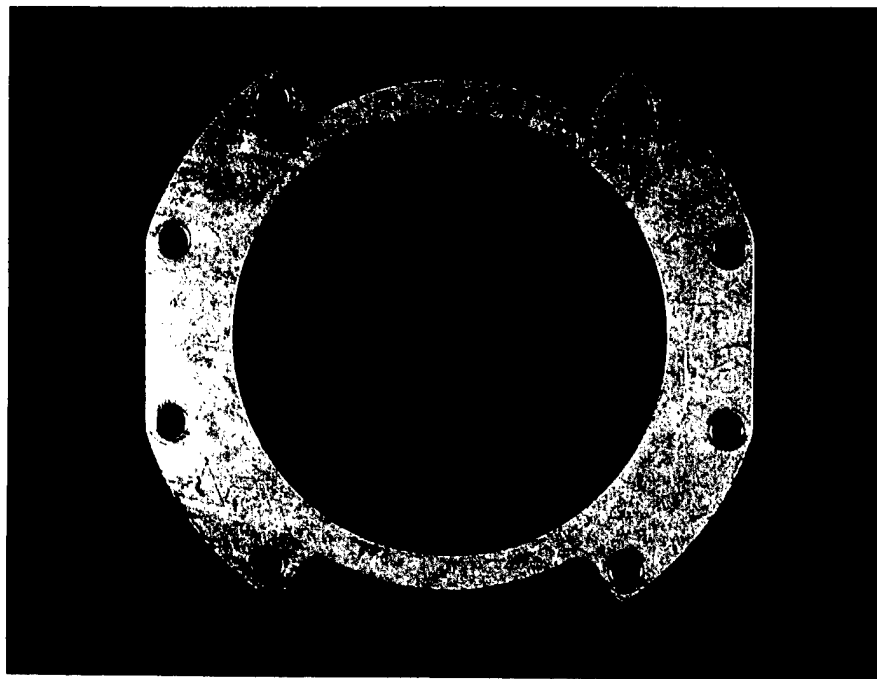


Cylinder Block Face 6,7,8

Cylinder Block Face after 1500 hrs.
Pump Test 36 with MIL-H-5606

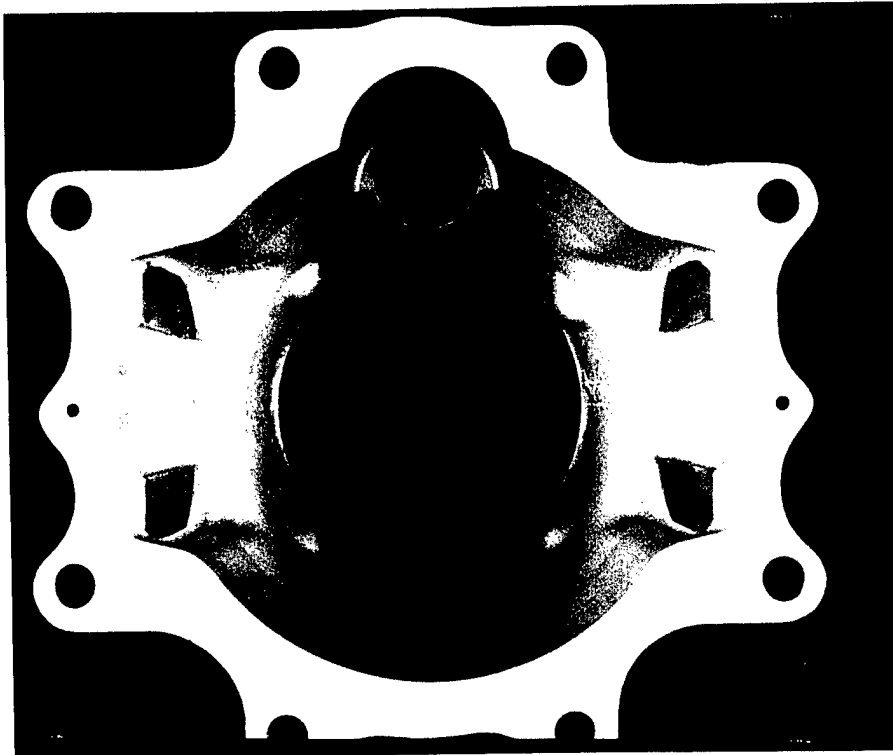


Rubbing Side

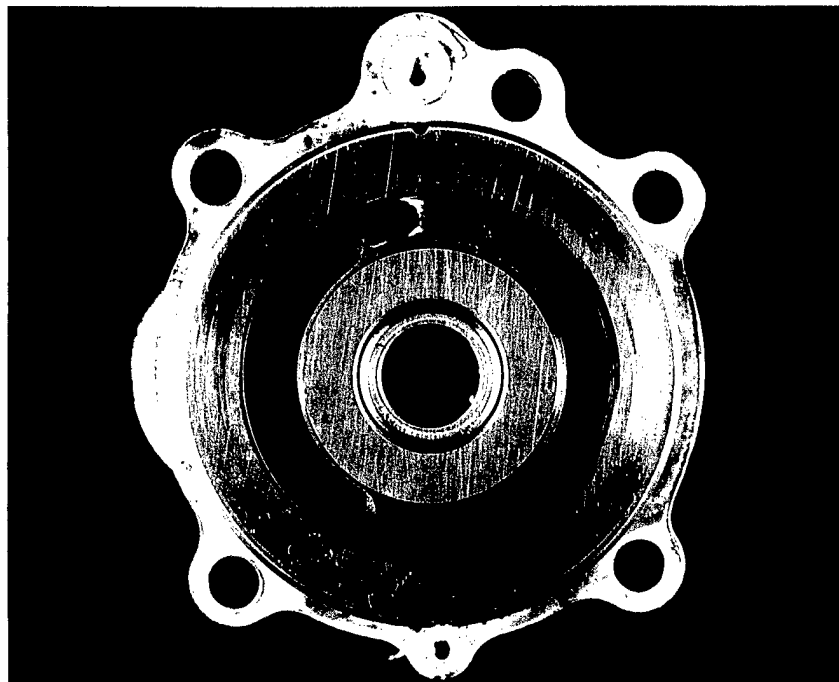


Non-Rubbing Side

Hold Down Plate after 1500 hrs.
Pump Test 36 with MIL-H-5606



Housing

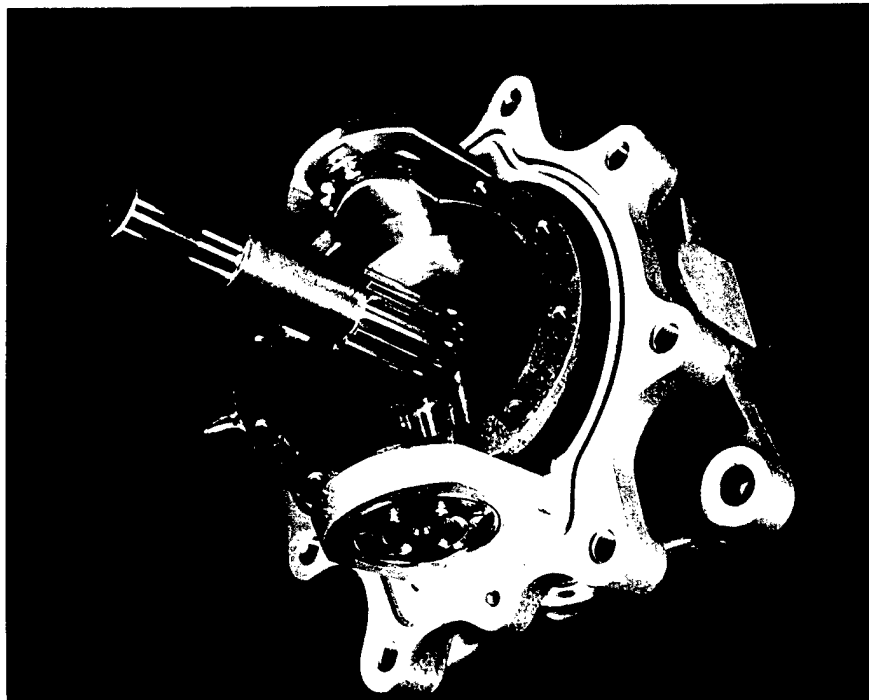


Cylinder Block Plate

Housing and Cylinder Block Plate after 1500 hrs.
Pump Test 36 with MIL-H-5606



Actuator Piston-Front View



Partial Assembly of Test Pump

Actuator Piston and Partial Assembly after 1500 hrs.
Pump Test 36 with MIL-H-5606